Aerofax Extra 4

NORTHROP B-2 *STEALTH* BOMBER

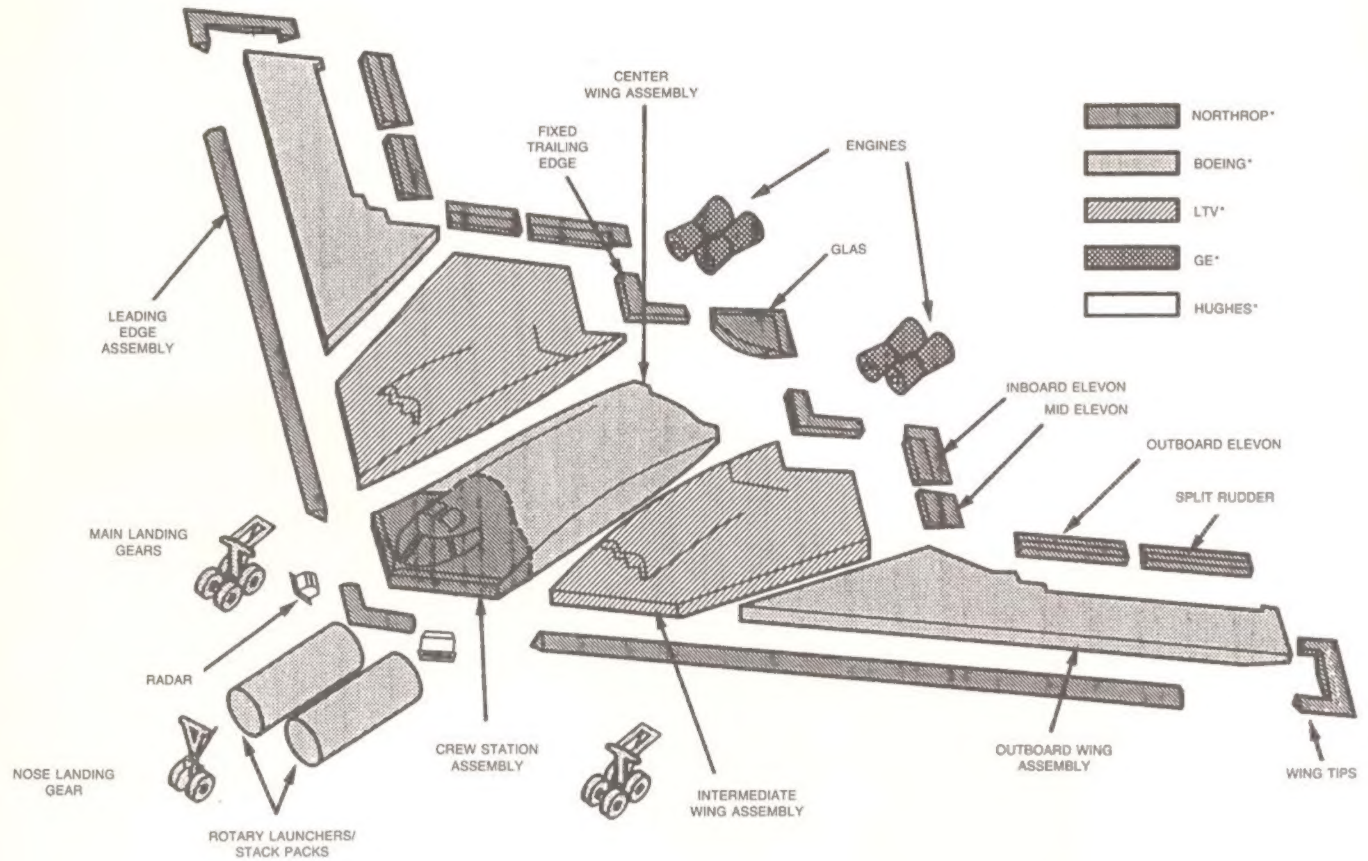
Northrop

Northrop B-2A, 82-1066, over Edwards AFB, California test range.

BY JAY MILLER

AMERICA'S *STEALTH* BOMBER DETAILED FOR THE FIRST TIME!

NORTHROP B-2 TEAM



Notional Depiction

ACRONYMS AND ABBREVIATIONS:

AAA	anti-aircraft artillery
ACES	Advanced Capability Ejection Seat
ADRAM	advanced radar absorbent material
ALCM	air-launched cruise missile
AMAD	airframe-mounted accessory drive
AMSA	Advanced Manned Strategic Aircraft
ASV	air-to-surface vessel
CIA	Central Intelligence Agency
CRT	cathode ray tube
DARPA	Defense Advanced Research Projects Agency
dB	decibel
DECM	defensive electronic countermeasures
ECM	electronic countermeasures
GHz	gigaHertz
HARP	Halper anti-radiation paint
Hz	Hertz
IFIS	integrated flight instrumentation system
IR	infrared
IRAM	improved radar absorbent material
IRCM	infrared countermeasures
km/h	kilometers per hour
kt.	knot
m.	meter
MHz	megaHertz
mi.	mile
mph	miles per hour
n.mi.	nautical miles
psi	pounds per square inch
RAM	radar absorbent material
RAS	radar absorbent structure
RCS	radar cross-section
RPV	remotely piloted vehicle
SAC	Strategic Air Command
SALT	Strategic Arms Limitation Talks
SCAD	subsonic cruise armed decoy
SLAR	side-looking airborne radar
WWII	World War II

THE NORTHROP B-2 "STEALTH BOMBER" STORY

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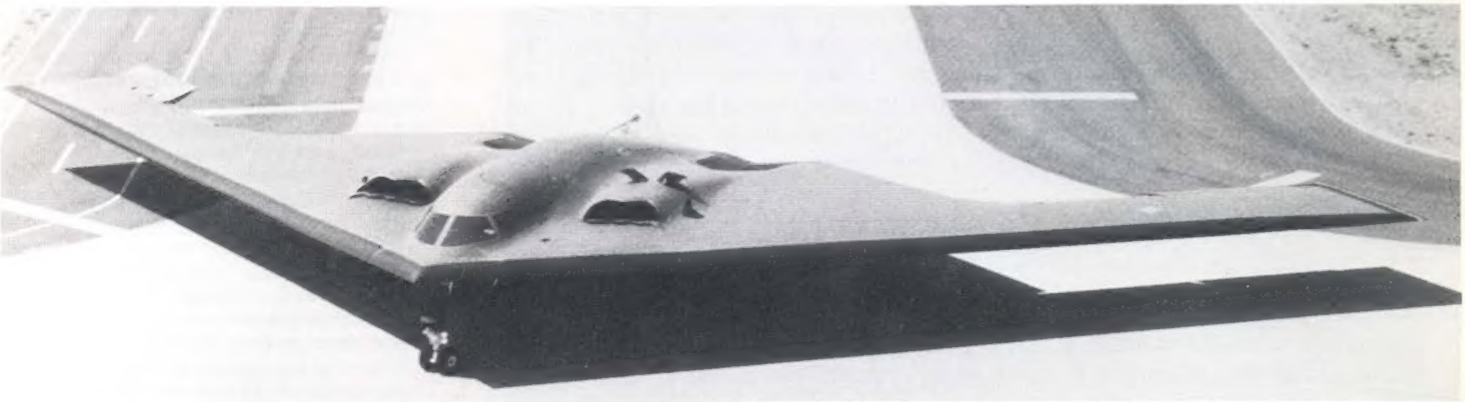

Top photo depicts the prototype B-2A, 82-1066, on the day of its formal roll-out, November 22, 1988, at Northrop's Palmdale, California production facility. Bottom photo depicts the aircraft during the course of its initial taxi trials which got underway, also at Palmdale, on July 10, 1989. Note open auxiliary intakes on the left engine nacelle.

DEDICATION:

This book is dedicated to my friend and fellow aviation enthusiast David Morgan. His love of airplanes and aviation history knew no bounds.

CREDITS:

This B-2 overview is the end product of contributions and efforts made on behalf of the author and Aerofax, Inc. by the following individuals: John Amrhein of Northrop Corporation, John Andrews of Testor Corp., Michael Binder, Paul Bower of LTV Aerospace, Terry Classon of Northrop Corporation, Tom Copeland, Charles Fleming, Jim Goodall, Kelly Green, Reuben Johnson, Tony Landis (special thanks), Chris Pocock, Ralph Poznecki, Ben Rich of Lockheed, Mick Roth, Robert Salvucci of GE Aircraft Engines, Bill Sweetman, Katsuhiko Tokunaga, Scott Vogel of General Electric, Barbara Wasson, and Dwight Weber of General Electric.

AUTHOR'S COMMENTS:

This booklet is the first attempt by any publisher to accurately describe the history of one of the most controversial U.S. military aircraft programs ever. Like the first Aerofax Extra describing Lockheed's enigmatic F-117 "stealth fighter" it is an initial attempt to provide the many curious among us with comprehensive textual and photographic coverage of an aircraft that is without precedent in the history of aerial combat.

Because of security constraints, information pertaining to the Northrop B-2 remains decidedly scarce. This booklet therefore represents a synthesis of all known unclassified and public domain materials coupled with select photographs from a variety of sources. As with the F-117, though much remains to be said about this aircraft, and considerably more will be released or leaked during the months and years ahead, this *Extra* represents a comprehensive summary to date, with considerable previously unpublished information and photography.

To those of you who own the *Aerofax Extra* describing the F-117, it will be apparent that there is some textual overlap in the first few pages of this *Extra* describing the B-2. Though the reasons for this are obvious, the author would like to emphasize that though the physical characteristics of the two aircraft are markedly different, their low observable philosophy is fundamentally the same. It thus is essential that the basic review of radar countering techniques be reiterated in this volume.

COUNTERING RADAR:

As with the Lockheed F-117, the basic objective of the B-2 design, from its inception, has been first and foremost to counter radar. To understand this requirement, and the stealth, or low-observables technology that's entailed, it is necessary to briefly review how air defense systems operate.

Virtually all air defense systems rely on radar as their primary sensor. The use of radar and radar-directed weapons such as air-to-air or surface-to-air missiles and anti-aircraft gunfire involves three inter-related disciplines:

(1) Surveillance—searching a broad volume of airspace to locate the target

(2) Fire control—establishing the target's current and future position, identifying whether it is friendly or hostile, and guiding some type of weapon to its immediate vicinity

(3) Kill—bringing a weapon close enough to the target to allow the weapon's fuse to detect the target and then detonate a warhead within lethal range.

Capable air defense systems must be able to carry out all three main functions reliably against all potential threats—if one function is done poorly, the net overall effectiveness is very low. Moreover, the air defense system must be able to survive direct attacks, resist countermeasures and adversary tactics, and function in the full range of atmospheric conditions.

Because of military radar's extreme importance in locating targets for destruction, extraordinary emphasis has been placed on its development and utilization as well as devices capable of overcoming or countering its capabilities. The latter, as was the case with the F-117, is what the B-2 is all about.

The B-2's design has been optimized to create the smallest radar target possible. Coupled with other "low observable" or "stealth" characteristics and technologies described later, it is a fourth-generation attempt to develop an aircraft that is virtually impossible to track continuously using radar as the targeting device.

Aircraft such as the B-2 dramatically reduce the effectiveness of all three basic air defense functions—surveillance, fire control, and kill—and thus increase their chances of survivability. Stealth reduces the size of signals available to the defense sensors which in turn

(1) Reduces the probability that surveillance, fire control, and kill will successfully occur, and if they occur, reduces the range at which they happen. A reduction of an aircraft's radar signature by a factor of ten reduces radar detection range to

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Cockpit assemblies of B-2As, AV-11 (front), AV-10 (middle), and AV-9 (back) are seen at Northrop's Palmdale, California facility being prepared for integration with other major B-2A subassemblies.

one-third its original value; a factor of 100 signature reduction reduces radar coverage area to one-tenth its original value.

(2) Weakens the defense system's ability to cope with interference from ground clutter, man-made noise, and false targets such as birds.

(3) Weakens the defense system's capability to cope with an adversary's tactics, such as flying at low altitudes or employing electronic countermeasures. This is an important additional attribute of stealth. Electronic jamming, for example becomes considerably easier and more effective when combined with stealth airframes. As the aircraft signature is reduced, the required jammer power and size also is reduced in proportion.

Overall, these effects on air defense systems provide stealth aircraft with a very high degree of survivability. Stealth aircraft are neither invisible nor immortal, but pose so many challenges to air defense systems that their survivability is much greater than conventional aircraft.

Basically, radar countering techniques (generally referred to as electronic countermeasures, or ECM) which now are readily found on virtually all operational combat aircraft and also are applicable to other military hardware as well, can be divided into two broad but basic categories—passive and active. The former involves the utilization of the physical characteristics of the aircraft to mask, within limits, its actual visibility, radar cross-section, active emissions (electronic, infrared, and otherwise), and any other aspect that would reveal its presence to an enemy; and the latter involves the use of systems that actively jam, deceive, or in any other way physically inhibit the enemy's ability to locate and destroy its target via electronic means. When combined, the two disciplines usually are referred to as defensive electronic counter-measures (DECM).

Granted that the objective is to interfere with an enemy's air defense system by inhibiting its sensors, there are basically three options:

1. Radiate active signals optimized to interfere with the enemy's radar.
2. Change the electrical properties of the medium through which the radar's energy is being transmitted (usually the atmosphere).
3. Change the reflective properties of the aircraft itself.

The first of these encompasses most jamming and deception systems; the second includes devices such as chaff and absorbing aerosols; and the last includes technologies utilizing the basic design of the actual vehicle, radar absorbent materials (RAM), and various types of echo distortion systems such as corner reflectors. A description of each follows:

1. Jammers can work in two ways—either by relying on brute force to overwhelm the hostile radar, or by confusing its accuracy. Some dual mode systems can do both. Types include:

(a) Noise jammers—these take the easy way out and attempt to drown the radar return from the target in an ocean of electronic noise. Noise jamming has many advantages. Relatively few electronic intelligence data are required, and the ECM device will affect anything operating on the frequencies being jammed. The design techniques are simple since the ECM is merely outshouting the hostile radar. Unfortunately, some of the methods for countering noise jammers are equally simple. The most obvious is to use frequency diversity (or "hopping") and to have a number of different radar frequencies on which to transmit.

(b) Spot noise jamming—represents the easiest method. A noise-modulated transmitter is set to operate on the frequency of the hostile emitter. This can be countered by enemy equipment fitted with a choice of operating frequencies.

(c) Swept-spot noise jammers—continuously scan a range of operating frequencies, interfering with each in turn. As long as all operating frequencies are covered, the threat radar will be regularly disrupted.

(d) Barrage jammers—are much simpler, radiating noise over the entire range of frequencies being covered, but for the same effect they need to be more powerful than spot jammers. Such equipment tends to be heavier than spot jammers, as well, but this is offset partially by the need for the latter to carry set-on receivers.

(e) Deception jammers are more complex than the noise generators described above and are based largely on the repeater principle, receiving the hostile signal then retransmitting it in modified or delayed form (in such a way that the radar thinks it is seeing an echo from another aircraft with a different position or velocity). Surveillance radars build up a picture of the surrounding airspace but tracking radars must concentrate on a single target. This normally is done by a process known as "gating". Once a target has been selected, a tracking radar does not listen continuously between output pulses from the target echo but only at around the time when the echo is expected. It thus is not confused by other targets nearer or further away from its antenna. As the target increases or decreases in range, the gate is moved accordingly. The interval of time between the radar output pulse being transmitted and the gated replay being received is used to measure target range. The gate effectively straddles the return signal within the radar receiver circuitry and is "smart" enough to move in time with the return. Signals outside the

gate are simply ignored. Typical deception techniques utilized by these jammers include range-gate pull-off, velocity track breaking, inverse amplitude modulation, inverse gain jamming, false target generation, buddy mode (using two aircraft), and cross eye (similar to buddy mode, but utilizing one aircraft with widely separated jamming system antennas).

2. There are basically two ways to change the electrical properties of the medium through which the radar's energy is being transmitted. The most common is via the use of small metallic strips called chaff (during WWII, chaff was referred to as "window") which works by affecting the propagation characteristics of the atmosphere, and the least common is through the very rare use of aerosols which contain metallic particulates.

Chaff operates to counter radar by creating and/or concealing targets, thereby creating confusion and delay. Chaff is used to assist aircraft in penetrating a radar network undetected and unidentified by creating a multitude of misleading targets or a large area of solid radar returns to confuse and mislead radar operators. Furthermore, even though the radar may locate the target, the addition of chaff induces errors in tracking radars and may disrupt tracking entirely. Chaff tends to saturate the capability of a radar and to create doubts, confusion, and hesitation among ground radar operators.

When first utilized during WWII against axis radar systems, chaff consisted of thin strips of aluminum foil with a length that was approximately half the wavelength of the radar being countered (today it is known that multiples of one-half the wavelength of the radar signal are suitable; this maximizes the sympathetic electrical resonance effect). The strips were purposefully made thin and light to enhance their ability to float in the atmosphere. Contemporary chaff generally is made of glass or plastic fiber material with a thin metallic film deposited on its surface. The lower density of these base materials enhances their float characteristics.

Chaff is dispensed in bundles or by machines that can provide strips of varying length in response to the immediate radar threat. For use against low-frequency radars (50 to 100 MHz), lengths of 5 to 10 ft. are common; lower frequency systems, such as those operated by the Germans during WWII, sometimes required chaff strips with lengths of 100 ft. or more.

3. By changing the reflective properties of the aircraft itself, the aircraft's radar cross-section can be modified to a startlingly great degree. It is, in fact, this specific technology that is the essence of the Northrop B-2's passive defensive system.

Work on materials that absorb, rather than reflect electromagnetic energy first was undertaken successfully by the Germans during WWII. The ability of allied aircraft-borne ASV (air-to-surface-vessel) radar systems to locate German submarine snorkels had proven a major frustration, and as a result, a rubberized RAM was developed under a program referred to as *Schornfeinsteger* (Chimneysweep). This proved a modestly effective method of lowering the radar return from the snorkels,

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The first three B-2As, 82-1066, 82-1067, and 82-1068 are seen nearing completion inside Northrop's Palmdale facility. Aircraft are completely covered with white, paperlike protective material prior to painting.

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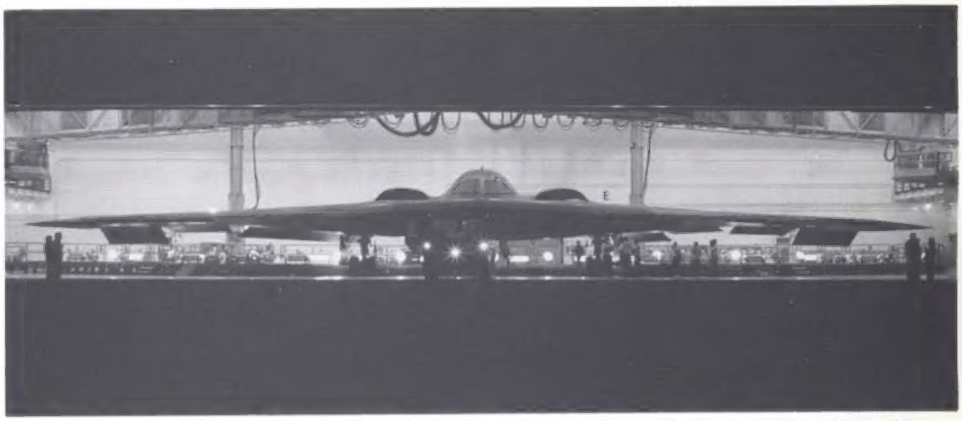

B-2A, 82-1066, being rolled from its Edwards AFB hangar in preparation for flight test. Readily visible in this view are distinctive heat guards over windscreen paneling and drooped control surfaces.

but it was far from foolproof—good radar operators often still could find the recharging submarines without significant difficulty.

Regardless, German RAM technology also was applied to other hardware, including aircraft. The most notable of the latter was the stunningly attractive Horton Ho IX. This tailless twin-jet fighter, perhaps the most advanced in the world at the time of its debut during 1944, was of primarily wood construction (with steel tube framing). Abbreviated test flights were conducted during January of 1945, and were followed by an order for twenty production samples under the designation Gotha Go 229.

Unknown to all but a few, Gotha's production Ho IX also was to become the first viable aircraft designed from the start to incorporate a rudimentary form of RAM. Though the three Ho IX prototypes (one, an unpowered aerodynamic glider serving as a testbed) had been built without it, the projected production aircraft would have utilized a wood-laminate skin consisting of two thin plastic-impregnated plywood sheets and a core material made of a sawdust, charcoal, and glue matrix. The latter, optimized to absorb radio energy and thus attenuate return reflections, was crude, but when coupled with the general construction materials of the rest of the aircraft, nevertheless contributed to what almost certainly would have been a very low RCS (radar cross section—i.e., the target's total reflected radiated energy).

Digressing for a moment, it should be noted that four basic factors determine the amount of reflected energy a radar will receive from a target during any one period of time that the antenna beam is trained on it: (1) the average power—rate of flow of energy—of the radio waves radiated in the target's direction; (2) the fraction of the wave's power which is intercepted by the target and scattered back in the radar's direction; (3) the fraction of that power which is captured by the radar antenna; and (4) the length of time the antenna beam is trained on the target.

Customarily, a target's geometric cross-sectional area, reflectivity, and directivity (the ratio of the power scattered back in the radar's direction to the power that would have been backscattered had the scattering been uniform in all directions—i.e., isotropically) are lumped together in what is called RCS (radar cross section). For computational purposes, this is represented by the Greek letter *sigma*, and usually is expressed in terms of square meters of area. The power density of the waves reflected back in the radar's direction, then, can be found by multiplying the power density of the transmitted waves

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A single Boeing C-135A, 60-0377, of the Air Force Systems Command, was extensively modified to serve as a testbed for the B-2A's highly complex navigation and bombing system. Numerous external mods are visible.

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Boeing C-135A, 60-0377 was equipped with special engine-mounted generators to provide power needed for B-2A systems. Visible above and below fuselage are special fairings for B-2A optical and electromagnetic sensors.

when they reach the target by the target's RCS. Since the directivity of a target can be quite high, for some target aspects, the RCS may be many times the geometric cross sectional area (the McDonnell Douglas F-15, for instance, has an actual area of approximately 25 m.^{2} when viewed from the side; its RCS, however, when viewed from the same aspect, is probably closer to 400 m.^{2}; additional aircraft for comparison include the Boeing B-52 with an equivalent RCS of 100 m.^{2}; the Rockwell B-1A with an RCS of 10 m.^{2}; and the Rockwell B-1B with an RCS of 1 m.^{2}). Interestingly, for select other aircraft, the reverse may be true.

Regardless, the further away from the radar a target is, the lower the strength of the return echo. Assuming an arbitrary strength of 1 at 1 mi., echoes from a standard target at 50 mi. range, for instance, are only 0.00000016 times as strong.

Though work on RAM and lowering RCS continued in many parts of the world during the closing stages of the war, its priority effectively remained low. During 1944, scientists at the prestigious Massachusetts Institute of Technology Radiation Laboratory created a ship-optimized RAM-type product referred to as "Halpern anti-radar paint" (HARP) with iron particulates suspended in a neoprene rubber base. This product proved only modestly effective and accordingly saw little use and eventually was discarded. Additionally, and perhaps more importantly, an Air Force-sponsored research project of approximately the same era resulted in the development of a paint referred to as MX-410, which also was a rubber-like matrix, though differing in having disc-shaped aluminum flakes in place of the iron particulates found in HARP.

With the post-1950s profligation of radar systems around the world and an ever-increasing surface-to-air missile barrier rising in what then was considered the main U.S. threat—the Soviet Union—interest in RCS and RAM technology began to resurface, though only as a secondary effort behind conventional elctronic countermeasures, and only at themost highly classified levels of government. In fact, the first aircraft created from scratch with RCS and RAM as integral elements of its design, Lockheed's A-12 high-speed, high-altitude reconnaissance aircraft, was a product of a Central Intelligence Agency requirement rather than that of any of the three major military services.

Work on the A-12 had been initiated during 1959, taking into consideration for the first time the fact that resonance effects on straight portions of reflecting skin materials greater than a half-wavelength in dimension will radiate perpendicularly to the surface when illuminated by radar. It was discovered, however, that if the same surface was curved, the resonance effect would be decreased by a mathematically computable ratio and the reflected energy would be distributed in several different directions. Thus curved surfaces returned considerably less energy to a radar receiver than flat.

With this in mind, Lockheed embarked on what was, to all intents and purposes, the first successful RCS-lowering blended fuselage design that combined aerodynamics with the exigencies of reducing the

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One of the oldest Boeing C-135As in the Air Force inventory, 55-3122, assigned to the Aeronautical Systems Division, was modified for use as a B-2A powerplant testbed. The inboard nacelle carried a single General Electric F118 turbofan engine. Mounted inboard of this, on a separate pylon, was a tank and pump assembly for chlorofluorosulfuric acid.

aircraft's radar return. Chines and wings were successfully blended with the A-12's two engine nacelles and a long, tubular fuselage to create the first Mach 3 cruise-capable aircraft in history. Though 102 ft. long and with a wingspan of 55 ft. 7 in., its total RCS was only .014 m.².

Blending of components in the A-12, however, was not the end of Lockheed's initial approach to what become known as "low observables" or "stealth" technology. In addition, the company integrated into the aircraft's basic design RAM-type structural elements called corner reflectors. These devices, which were integral with the wing and fuselage chine leading edge surfaces (thus giving the leading edge surface paneling a saw-tooth or dog-tooth look) were formed from two intersecting, mutually perpendicular metal (titanium) sheets. When installed, they reflected energy like any other metal surface, but the difference was their triangular configuration created a very effective energy trap. In the A-12, for additional attenuation, a pyroceramic insert matrixed with its own attenuators was used as a filler to give the wing leading edge continuity, aerodynamic and structural integrity, and the ability to withstand the rigors of cruising flight at three times the speed of sound.

RAM, it was discovered, could be manufactured from a wide variety of materials with each providing a unique or energy-specific capability. Concerning the latter, RAM was found to be most efficient when utilized in thicknesses that were dimensionally a quarter of the specific wavelength being attenuated and also permeable to electromagnetic energy. When applied in layers, energy reflected repeatedly between each was rapidly dissipated and returns were minimized.

Unfortunately, first-generation RAMs came with a hefty price. In many instances, they were applied to external parts of the aircraft and were not load-bearing, and this resulted in both aerodynamic and weight penalties. With the sole exception of the then-highly-classified A-12 (and, it should be mentioned, one of its never-to-be-built competitors, General Dynamics' highly-classified *Kingfish* project; the latter was to have been manufactured almost entirely of pyroceram; it would have been capable of Mach 6.25 at an altitude of 125,000 ft.), they were rarely considered as integral elements of the airframe.

Topping off the attention to lowering the A-12's RCS was a covering of radar absorbent paint (initially this was applied to the most reflective elements, only; later the entire aircraft was painted). Basically a matrix consisting of a suspension base (epoxy) and ferrite (iron) particulates, it worked on the same fundamental principles of other RAMs in that the molecular structure was optimized to absorb (in the form of "free electrons" actively converted to heat) as much of the incoming radar energy as possible. Though only modestly effective (much of the radar's energy was still reflected), when combined with other design techniques and the more aggressive forms of structural RAM, it provided a rather large payoff in lowering the aircraft's total RCS.

To date, little information has entered the public domain concerning the various RAMs and their physical characteristics. The following list, however, was provided by Plessey Microwave of England and gives some insight into this relatively esoteric subject:

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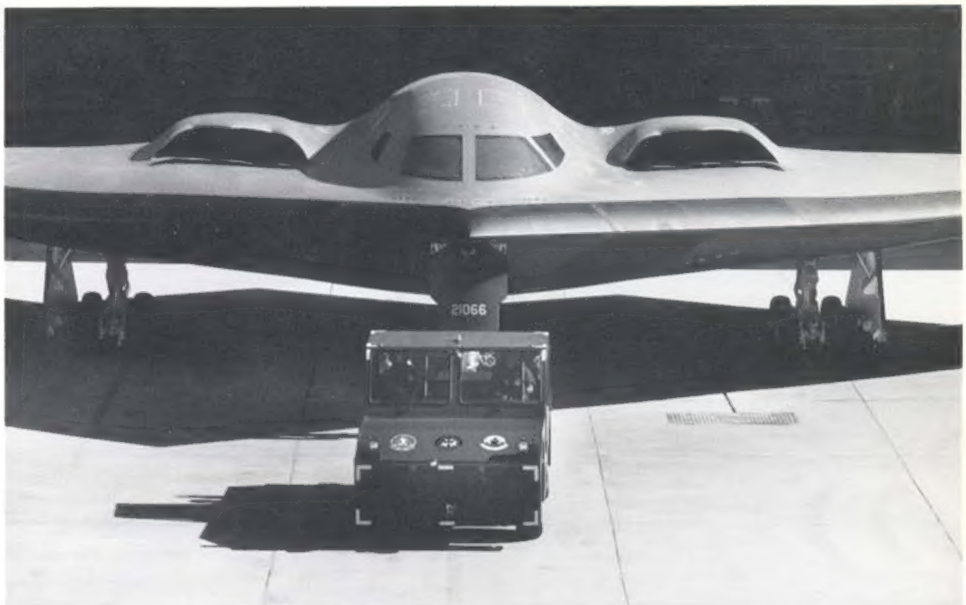

Roll-out of the first B-2A, 82-1066, took place on November 22, 1988. One of the aircraft's most immediately noticeable features was the uncompromised blending of virtually every panel on the aircraft.

Jay Miller/Aerofax, Inc.

B-2A, 82-1066, during the June 1991 "Stealth Week" display at Andrews AFB, Maryland. Readily visible are the drooped trailing edge surfaces, the overwing intake placement, and the wide main gear stance.

A-1 Netting—a broadband, moderate-performance, low-cost material covering 4 GHz up to 94 to 100 GHz. Main applications are reducing RCS outside installations such as hardened aircraft shelter doors. For it to be utilized in harsh environments, it must be encapsulated in a PVC or plastic envelope. It has numerous applications.

Salisbury Screen—if material is needed to work down at a lower than normal operational frequency, it can be utilized in this form, which consists of a back-reflecting mechanism such as a wire mesh, metallic mesh, sheet material, or even a garden fence. There is a dielectric airspace between the absorber on the front surface and the rear surface, with the distance calculated depending on the operating frequency required. At 1 GHz its performance is increased from about 12 or 15 dB to about 20 dB. There is a third harmonic performance from the base frequency (1 GHz) at 3 GHz, 5 GHz, 7 GHz, and so on.

IRAM—the base material for this is horsehair packing (exactly the same as commonly available for other, more domestic requirements). Its main use is to absorb stray energy and sidelobes from communication antennas. It is inexpensive, but it has only moderate performance in the 15 dB range, having a frequency excursion of about 4 GHz up to 16 GHz. It is available in sheets with sizes of 8 ft. by 2 ft.

LA O ("La Nought")—a high-performance material consisting of reticulated polyurethane foam treated with carbon emulsions. Its performance (frequency range) is dependent upon the thickness required. At 6 mm., it would have a high-performance broadband from approximately 20 GHz up to 100 GHz; in 12 mm. thickness the bottom frequency would improve with coverage of from 4 GHz to in excess of 50 GHz; in the 2 in. thick version a bottom operating frequency of 1 to 1.5 GHz would be possible, but reasonable performance would occur in the 30 to 50 GHz range. This product has many applications ranging from antennas to missile nosecones. If LA O is "foamed through" with a low-loss dielectric foam, its characteristic is changed into a flexible sheet which is very rigid with a high mechanical strength. In this form, it can be fabricated or molded into virtually any shape desired. Where weight is a significant problem, and flexibility of the product is required, LA O can be machined into whatever form is required.

ADRAM (Advanced Dielectric Radar Absorbent Material)—the base material for this product is polyurethane, but it is loaded with dielectric (plastic or insulating) material. Performance is similar to that of the narrow-band materials. It has a high angle-of-incidence property (it can operate

B-2A, 82-1066, during the course of initial high-speed taxi trials at Palmdale, California. Noteworthy are open auxiliary intake doors on the top of the left engine nacelle and the position of the trailing edge surfaces.

Lift-off of B-2A, 82-1066, at the time of its first flight on July 17, 1989. The flight was conducted from Palmdale and ended at Edwards AFB, taking some 2 hours and 20 minutes. Noteworthy is "beaver tail" position.

Another view of the lift-off of B-2A, 82-1066 at the beginning of its first flight. Split drag rudders in normal, open position are readily discernible. All other surfaces are symmetrically faired.

B-2A, 82-1066, moments before touching down at Edwards AFB, California. Auxiliary intake doors are open, the "beaver tail" is in its trailing edge down position, and the main landing gear are only inches from the runway.

at angles-of-incidence in excess of 120° included angle) whereas the narrow-band materials operate at plus or minus 50°. The need for high angle-of-incidence performance is to get multi-bounce, multi-path reflections of high-energy, whereas the single-tuned frequencies operate at (basically) 90° to the incoming signal (the original single-frequency materials were used on various aircraft projects during the 1950s, but weight problems precluded widespread use).

Sheet Materials—using rubbers, nitriles, silicones, and polyurethanes as bases, it is possible to load them with various magnetically-loaded products such as ferrous materials, carbons, and high-performance dielectrics. These are high-performance narrow-band items which can be manufactured in moldings which bond two materials together (for example, one tuned to S-band and one tuned to X-band). The performance is in excess of 25 dB at the chosen operating frequencies. Application is limited because of weight.

Additionally, during the early 1960s, it is known that Lockheed developed and flight tested a first-generation RAM product utilizing a Salisbury Screen and a rubberized coating called Echosorb. This matrix was tested extensively by the company as a U-2 undersurface coating before being shelved due to general ineffectivity and maintenance difficulties. Still more recently, the Japanese company, TDK, revealed that it sells a commercial RAM consisting of two ferrite layers with different characteristics that can be utilized to absorb microwaves for commercial purposes (such as on tall buildings to absorb television signals or corrected problems with television ghosting).

As important as radar return attenuation is to the philosophy of low observables technology, it remains equally as important to mask other detectables, as well. It therefore becomes mandatory that visual, infrared (IR), acoustical, and exhaust emission signatures be minimized with equal intensity. All entail active design considerations and they have been addressed with considerable success by the U.S. military aerospace industry.

Infrared radiation is electromagnetic radiation with a dual quality. The principle feature distinguishing IR from radar energy is its position in the electromagnetic spectrum. The frequency of IR radiation extends from approximately one-million to five-hundred-million MHz. In the frequency spectrum, IR falls between the upper limit of microwaves and the lower limit of light. As a result of this, it exhibits some of the characteristics of both. IR, interestingly, can be transmitted through materials opaque to visible light, and IR also can be optically focused by lenses and mirrors. Any material whose temperature is above absolute zero (zero degrees on the Kelvin temperature scale or minus 273° centigrade) generates IR radiation. If the material is heated, not only does the kinetic energy of the molecules increase, but also the electrons in each atom are raised to a higher energy level. As the material cools, it gives up this energy and the electrons fall back to their original energy level. This energy level change causes electromagnetic radiations, some of which fall into the IR wavelength range. Because IR is produced by warm materials and because temperature dictates the characteristics of the radiation from these materials, IR energy often is referred to erroneously as "heat". IR is not heat, but depends on heat for generation.

The development of IR systems has been paral-

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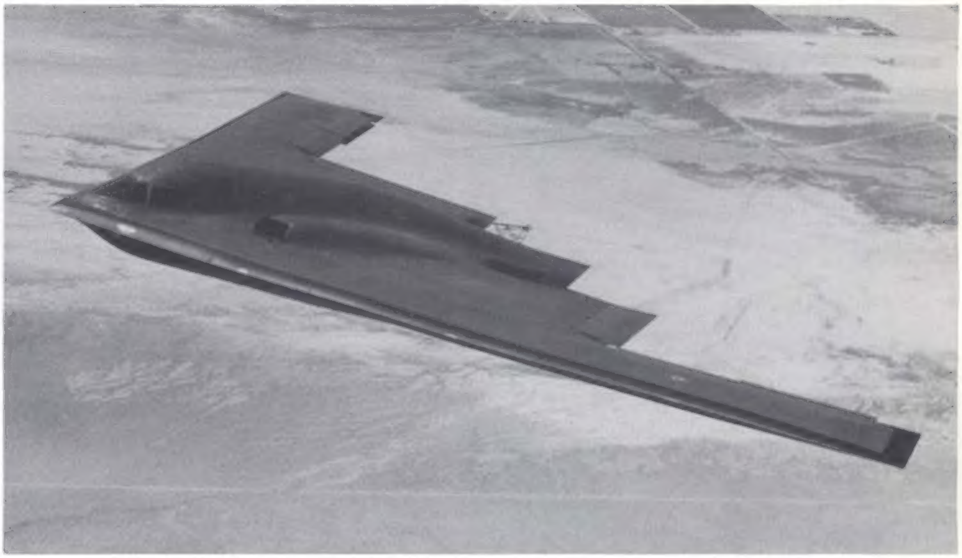
First flight test pilots were Northrop's Bruce J. Hinds (left) and Air Force Col. Richard S. Couch.

USAF



B-2A, 82-1066, provides view of unusual and complex nose contour not usually visible from front or top perspective. Leading edge complexity also is apparent somewhat in this view (note tip taper).

leled by a search for effective IR countermeasures (IRCM). IRCM can be either specifically designed equipment to affect the target homing ability of an IR seeker, or it can be specific tactics designed to affect target discrimination ability. Importantly, through passive elements such as design, the detectability of a target such as an aircraft may be decreased by shielding the hot components of an engine from view or by reducing the engine operating temperature.

Efficient use of some IRCM requires warning of the presence of an IR threat. Since IR systems can attack without the use of a supporting radar search and track system for acquisition, airborne IR warning receivers have been developed to passively detect the presence of the attacker's exhaust plume. Airborne IR warning receivers are capable not only of detecting the presence of an airborne interceptor, but of detecting the launch of an air-to-air missile. Once the IR homing missile has been launched, IR countermeasures can be employed.

One IR countermeasure is the introduction of smoke into the exhaust of the target aircraft's jet engine(s) to diffuse engine-generated IR radiation. This, however, tends to be somewhat counterproductive, as the smoke itself becomes a visual clue as to where the aircraft is located.

Another IRCM is the flare. Flares are designed to produce a more intense source of IR radiation than the target aircraft's jet engines. The flare is ejected from the aircraft and as it falls away, the IR homing missile will track the flare and not the original target aircraft. The major disadvantage of flares is that only a limited number can be carried.

Another IRCM is the use of a powerful IR source, such as a heat-generating lamp, that can be installed in an aircraft's tail. By blinking the lamp on and off at a predetermined rate, an IR homing missile can be deceived in much the same way that a radar can be angle deceived. The advantage of this IRCM is that the supply is unlimited.

Tactical maneuvering is another IRCM form. The aircraft may be able to evade the IR seeker's field of view, or it may be possible to maneuver so as to orient the missile's IR detector to face the sun. If the latter is successful, the missile will not be able to separate the target from background radiation. Yet another countering technique is to maneuver into a cloud bank where water droplets and dust particles will absorb and scatter the pursued aircraft's IR radiation.

Integration of passive IRCM elements into the basic airframe design is best represented by the latest fighters and bombers under development for the U.S. military services. With the Lockheed F-117, Northrop B-2, and to a lesser extent, the new Lockheed/General Dynamics/Boeing F-22, engineers have gone to great lengths to ensure that the infrared signatures of the aircraft have been kept to an absolute minimum.

In the case of the F-117, the exhaust gases are mixed with relatively cool ambient air in a plenum just aft of the engines. Once mixed, the exhaust then passes through a horizontal slot-type nozzle assembly (sometimes referred to as a "platypus" nozzle) that is some six feet wide and approximately six inches deep. This slot is divided into twelve separate ports which serve to channel the exhaust gases into an extended lower lip created from the aircraft's flattened empennage. There the exhaust gases are mixed rapidly with outside ambient air. By the time they enter the aircraft slipstream, temperature levels have been lowered significantly and the exhaust plume presents a minimal infrared target.

In years past, the visual and acoustical signatures of an aircraft were given only passive consideration. Though research met with considerable success in reducing combustion and particulate smoke emissions, this was not considered a high-priority concern until it became a source of contention during the course of the Vietnam War. At the same time, acoustical elements were all but ignored.

With today's emphasis on low-observables, visual and acoustical signatures have been given high priority. Visual elements have been deemphasized by reducing the aircraft size wherever possible, minimizing component cross sectional area, reducing light reflectivity, significantly reducing engine exhaust emissions (in particular, particulates resulting from combustion), and optimizing airframes so that low-altitude (terrain following) routing to targets can be utilized (thus limiting exposure times for ground-based anti-aircraft systems and observers).

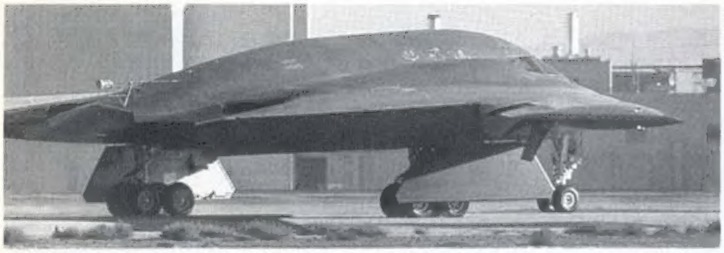
Acoustics have been addressed through the utilization of innately quieter turbofan engines, optimum intake and exhaust configurations, and improved materials technology. Fortunately, some aspects of infrared attenuation such as deeply recessed exhaust nozzles automatically reduce an aircraft's lower hemisphere acoustical signature without significant additional effort.

In the high-altitude penetration arena, particular emphasis has been placed on the reduction of engine exhaust plume contrail development. Work in this field has been ongoing for many decades, and as of this writing, the primary means of contrail reduction involves the injection of fluorochlorosulfuric acid into the exhaust gases. This highly toxic and caustic chemical is carried in a separate tank aboard both the F-117 and B-2 and is said to completely eliminate contrail formation when used.

Concern remains, as of this writing, over the possibility of one or several low-observables countering techniques being developed by enemy forces. Accordingly, during the course of on-going low-observables development, a number of still-classified studies have been conducted exploring the various countering options that could conceivably evolve into operational systems. If such vulnerability has surfaced, the fact remains hidden from the public domain, but to date, the Air Force and associated research institutions and facilities all have categorically denied vulnerability to any known detection technology.

Some twenty-eight counter-low-observables techniques are known to have been explored by the Air Force including: acoustical systems; ground-based and airborne bistatic radar; anti-stealth radar waveforms; balloon-borne radar; bistatic reflector systems; corona detection; spectroscopy correlation; cosmic ray anomalies; differential electromagnetic spectrum absorption; infrared airborne warning and control systems; infrared search and track; magnetic anomaly detection; space-based radar systems; upgraded contemporary radar systems; over-the-horizon radar; passive coherent detection; radar shadow detection; hybrid bistatic radar; aircraft emission detection; impulse radar; tower and net systems; advanced airborne surveillance; radar wake detection systems; radiometers; ultra-wide band radar; polysaturation Doppler radar; and high-frequency radar.

Information released by the Air Force to date indicates the B-2 can penetrate without allowing adequate vectoring of enemy fighters; limits the range of detectability by enemy fighters to meaningless intercept distances; and reduces the effectivity envelope of surface-to-air missiles to a minimal window of vulnerability.

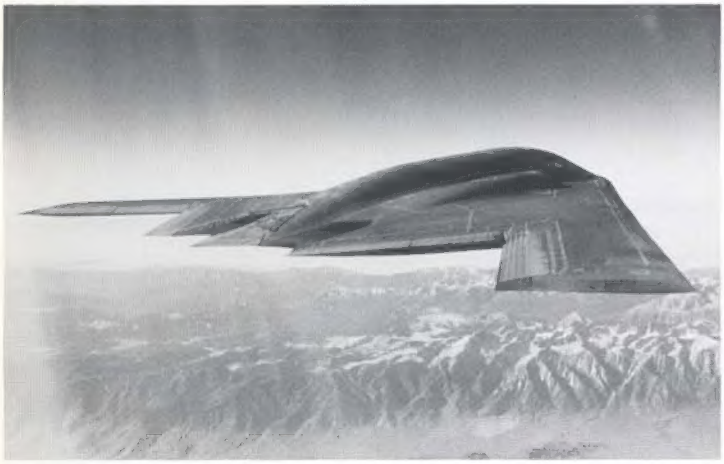


Northrop

B-2A, 82-1066, during July 1989 taxi tests. At aft end of fuselage is "beaver tail" pitch control and trim surface, and temporary airspeed calibration device.

Jay Miller/Aerofax, Inc.

B-2A, 82-1066, was displayed during "Stealth Week" at Andrews AFB, Maryland with one of its two bomb bays open and two of its four engine bays open.



Northrop

Tuft testing (note drag rudders), to determine the presence of any previously unpredicted airflow anomalies were conducted early in the B-2A flight test program.

USAF

Though appearing simple, the B-2A is an aerodynamically complex and highly refined aircraft. Noteworthy in this view is the assymetrical leading edge configuration.

B-2:

On August 22, 1980, the following statement by then-Secretary of Defense Harold Brown (under President Jimmy Carter) was released to the public:

"I am announcing today a major technological advance of great military significance.

"This so-called 'stealth' technology enables the United State to build manned and unmanned aircraft that cannot be successfully intercepted with existing air defense systems. We have demonstrated to our satisfaction that the technology works.

"This achievement will be a formidable instrument of peace. It promises to add a unique dimension to our tactical forces and the deterrent strength of our strategic forces. At the same time it will provide us capabilities that are wholly consistent with our pursuit of verifiable arms control agreements, in particular, with the provisions of SALT II.

"For three years, we have successfully maintained the security of this program. This is because of the conscientious efforts of the relatively few people in the Executive Branch and the Legislative Branch who were briefed on the activity and of the contractors working on it.

"However, in the last few months, the circle of people knowledgeable about the program has widened, partly because of the increased size of the effort, and partly because of the debate underway in the Congress on new bomber proposals. Regrettably, there have been several leaks about the stealth program in the last few days in the press and television news coverage.

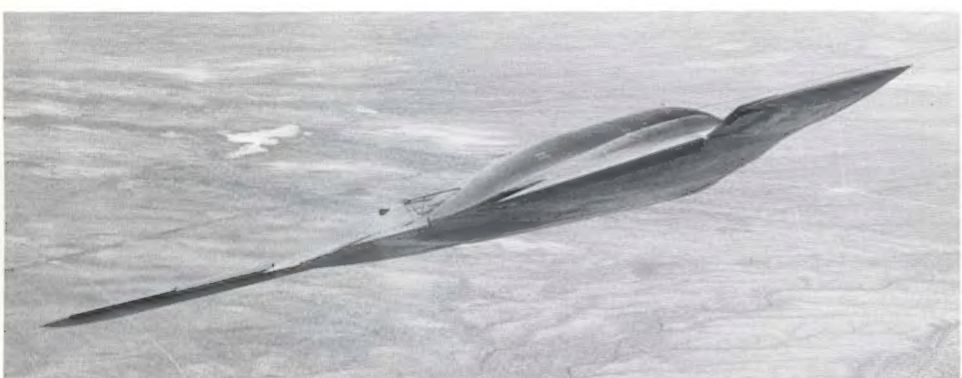
"In the face of these leaks, I believe that it is not appropriate or credible for us to deny the existence of this program. And it is now important to correct some of the leaked information that misrepresented the Administration's position on a new bomber program. The so-called stealth bomber was not a factor in our decision in 1977 to cancel the B-1; indeed, it was not yet in design.

"I am gratified that, as yet, none of the most sensitive and significant classified information about the characteristics of this program has been disclosed. An important objective of the announcement today is to make clear the kinds of information that we intend scrupulously to protect at the highest security level. Dr. Perry, my Under Secretary of Defense for Research and Engineering and a chief architect of this program will elaborate this point further.

"In sum, we have developed a new technology of extraordinary military significance. We are vigorously applying this technology to develop a number of military aircraft and these programs are showing very great promise.

"We can take tremendous pride in this latest achievement of American technology. It can play a major role in strengthening our strategic and tactical forces without in any way endangering any of our arms control initiatives. And it can contribute to the maintenance of peace by posing a new and significant offset to the Soviet Union's attempt to gain military ascendancy by weight of numbers.

"I would like to ask Bill Perry to give you some additional details on our stealth program."



USAF

One important design consideration of low-observables technology is that of physical visibility. Accordingly, the B-2A has been configured to provide a minimal visual profile from virtually any angle.

Under Secretary of Defense for Research and Engineering William Perry's comments were:

"World War II demonstrated the decisive role that air power can play in military operations. It also demonstrated the potential of radar as a primary means of detecting aircraft and directing fire against them. On balance, though, the advantage clearly was with the aircraft. Subsequent to World War II, defensive missiles—both ground launched and air launched—were developed and 'married' with radar fire control systems. This substantially increased the effectiveness of air defense systems, shifting the balance against aircraft. For the last few decades we have been working on techniques to defeat such air defense systems. At present, our military aircraft make substantial use of electronic countermeasures (jamming) and flying low to place themselves in 'ground clutter', both of which degrade the effectiveness of air defense radars. By these means we have maintained the effectiveness of our military aircraft in the face of radar-directed defensive missiles.

"However, the Soviets continue to place very heavy emphasis on the development and deployment of air defense missiles in an attempt to off-

Northrop

The first two B-2As, 82-1066 (left) and 82-1067 at the Air Force's Edwards AFB, California facility. The aircraft are physically virtually identical, though internal test system requirements have dictated many equipment differences. As of this writing a third aircraft has joined the flight test force at Edwards.

set the advantage we have in air power. They have built thousands of surface-to-air missile systems, they employ radars with high power and monopulse tracking circuits which are very difficult to jam, and in the last few years they have developed air-to-air missiles guided by 'look down' radars which are capable of tracking aircraft in 'ground clutter'.

"Because of these developments and because of the importance we attach to maintaining our air superiority, we have for years been developing what we call 'penetration' technology; the technology that degrades the effectiveness of radars and other sensors used by air defense systems. A particular emphasis has been on developing that technology which makes an aircraft 'invisible' (a figure of speech) to radar. In the early 1960s, we applied a particular version of this technology to some of our reconnaissance aircraft. In the mid-1970s we applied it to the cruise missiles then being developed (*Tomahawk* and ALCM). By the summer of 1977 it became clear that this technology could be considerably extended in its effectiveness and could be applied to a wide class of vehicles including manned aircraft. We concluded that it was possible to build aircraft so difficult to detect that they could not be successfully engaged by any existing air defense systems. Recognizing the great significance of such a development we took three related actions; first, we made roughly a ten-fold increase in our investment to advance this technology; second we initiated a number of very high priority programs to apply this technology; and third, we gave the entire program extraordinary security protection, even to the point of classifying the very existence of such a program.

"Initially we were able to limit knowledge of the program to a very few Government officials in both the Executive and Legislative Branches and succeeded in maintaining complete secrecy about the program. However, as the program increased in size—currently the annual funding is 100 times greater than when we decided to accelerate the program in 1977—it became necessary to brief more people. The existence of a stealth program has now become public knowledge. But even as we acknowledge the existence of a stealth program, we will draw a new security line to protect that information about the program which could facilitate a Soviet countermeasures program. We will continue to protect at the highest security level information about:

a. the specific techniques which we employ to reduce detectability;

b. the degree of success of each of these techniques;

c. characteristics of specific vehicles being developed;

d. funds being applied to specific programs; and

e. schedules of specific programs.

"With those ground rules, I think you can see that I am extremely limited in what I can tell you about the program. I will say this. First, stealth technology does not involve a single technical approach, but rather a complex synthesis of many. Even if I were willing to describe it to you, I could not do it in a sentence or even a paragraph. Second, while we have made remarkable advances in the technology in the last three years, we have been building on excellent work done in our defense technology program over the last two decades. Third, this technology—theoretically at least—could be applied to any military vehicle which can be attacked by radar-directed fire. We are considering all such applications which are the most practical and which have the greatest military significance. Fourth, we have achieved excellent success on the program, including flight tests of a number of different vehicles."

As Brown and Perry implied, the US defense community, including both private sector and government entities, had been studying the attributes of low-observables technology for a considerable period of time. Several companies, including most notably Lockheed, Northrop, and General Dynamics, had in fact manufactured hardware specifically designed with low-observables objectives as an integral part of the finished package. Lockheed's crowning glory to this point was the Central Intelligence Agency's Mach 3-plus-capable A-12; Northrop had developed a family of low-observable drones and had initiated studies calling for manned aircraft built to the same standard; and General Dynamics had devoted a considerable amount of time and money to its SR-71 competitor, the little-known all pyroceramic Mach 6.25-capable *Kingfish*.

Technically, the A-12 and *Kingfish* resulted in what many today call "first-generation" stealth technology. In turn, during the mid- and late-1970s, they were followed by various levels of "second-generation" stealth including the little-known Lockheed *Q-Star*—with its extremely low acoustical, infrared, and emissions signatures—and the now highly-publicized "third-generation" Lockheed F-117 "stealth fighter" with its extremely low radar cross-section and minimalized infrared and exhaust emissions signatures.

Numerous other still-sensitive and essentially still-black programs reached fruition during this period, including a modest family of remotely piloted vehicles (RPVs), select cruise missiles, and a still-under-wraps series of manned testbeds developed by Northrop, Boeing, General Dynamics, and Lockheed, to name a few. One of Lockheed's testbeds, the *Have Blue* predecessor to the F-117 (see *Aerofax Extra Lockheed F-117 Stealth Fighter*), has only recently been unveiled—nearly a decade-and-a-half after it first was conceived and brought to life at the hands of Lockheed *Skunk Works* chief, Ben Rich.

In the midst of all this industry-wide low-observables design activity, the U.S. Air Force, fronting for work then being sponsored by the Defense Advanced Research Projects Agency (DARPA), began to consider not only the application of stealth to various aspects of a combat aircraft's basic design, but also the possibility of letting stealth be the driving force behind the aircraft's over-all configuration and construction. Already, early signs of this had begun to appear in such publicly-acknowledged aircraft as the SR-71 and the Rockwell International B-1A and B-1B. These configurations, however, had been compromised in favor of different mission and per-


Northrop

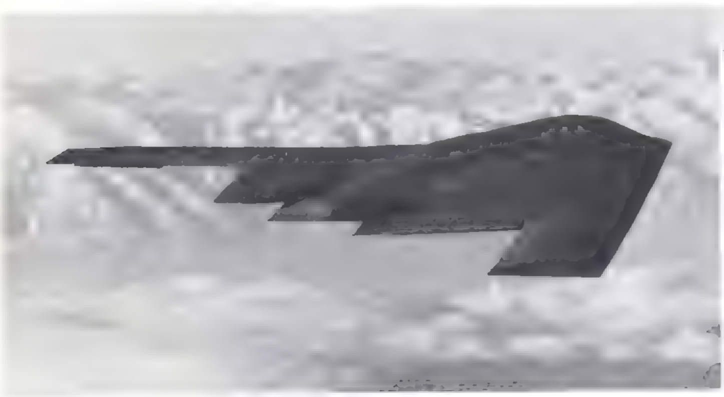
"Do Not Walk" areas are clearly marked with low visibility paint on the B-2A's upper surfaces. USAF serial number and affected commands are visible aft of the cockpit.


Northrop

B-2A, 82-1067, in flight near Edwards AFB. Upper surface markings vary slightly from 82-1066. Aft of cockpit, is what appears to be a night formation strip light.


USAF

Near head-on view of B-2A, 82-1066. Aircraft frontal area is minimal from both an aerodynamic and visibility standpoint. Note slight variations in wing leading edge camber, not visible from directly above or below. Cockpit visibility forward appears excellent, but view to either side or rear is virtually non-existent.


Northrop

To date, an altitude of just over 45,000 ft. (13,720 m.) and a speed of 460 mph (741 km/h) have been achieved during the course of the B-2A's flight test program.


Northrop

Test pilots have been quick to complement the B-2A's ease of control and over-all stability in flight resulting from its highly advanced flight control system.

Northrop

Final approach configuration of B-2A. Split drag rudders are most prominent trailing edge surface feature. Other surfaces remain essentially faired with exception of pitch trimming "beaver tail".

Northrop

Beak-like nose and tapering leading edge camber arrangement are readily apparent in this view of B-2A, 82-1066, possibly during the course of its second flight. Chase aircraft is General Dynamics F-16A.

formance priorities. Both the SR-71 and B-1 had been designed from the start to be supersonic-capable. This had dictated materials choices and structural design elements and thus had lowered the prospects of minimalizing RCS and IR signatures.

In the interim, the rapidly maturing science of high-strength composites had become a leading materials contender in the aircraft industry. Though composites, in one form or another had been around for decades, and in fact had served as dielectric covers for radar and various antennas almost since the advent of their development, they had rarely, if ever, been utilized as load bearing structural elements.

Perhaps the first to look at composites seriously as load-bearing aircraft structural components had been Midland, Texas-based Dr. Leo Windecker. During the mid-1960s, his Windecker Aircraft company had built and test-flown the first of a small run of what then were referred to as "all-plastic" aircraft. Named Windecker *Eagles*, they were aesthetically pleasing but suffered from only average performance and a markedly conservative customer base. The latter proved somewhat gun-shy of unconventional materials technology.

Windecker's pioneering composites work, which had been initiated during 1959 and first had surfaced in hardware form during 1960 and 1961 with the flight testing of a "plastic winged" *Monocoupe*, effectively had exposed the attributes of such materials for aircraft construction. Though the Windecker *Eagle* died after only eight aircraft were completed, the last of these, built to a military contract and designated YE-5, played an exceptionally influential role during the course of the forthcoming U.S. military's low-observables design thrust.

Leo Windecker's interest in composite construction had sprung from his belief that strong aircraft built from such materials could be produced rapidly, relatively inexpensively, and to a consistently high quality standard. At the time, neither he nor anyone else was in a position to see there was a hidden attribute that would become even more precious than all the others put together....composites, and their other plastic siblings, were radar transparent. Electromagnetic energy simply passed through with virtually no attenuation or reflection whatsoever.

Early tests of Windecker prototypes had revealed inadvertently what then was considered to be the bothersome "attribute" of transparency when ground controllers at the Midland-Odessa Regional Airport found the aircraft difficult, if not impossible to track on local radar. It later became necessary to install aluminum foil strips inside the composite laminates to bring the radar return up to a suitable level.

The small YE-5 contract let on February 23, 1973 and the analysis that followed near the end of the Windecker company's short life initially were not paid significant attention. However, as evolutionary trends partially dictated by projected threat scenarios began to evolve, a slow swing in the direction of low-observables began to surface.

The war in Vietnam, still on-going at the time Windecker received its YE-5 contract, revealed innumerable failings in U.S. air combat technique and philosophy. North Vietnam's successes with low-altitude anti-aircraft artillery (AAA), for one, proved considerably higher than anyone originally had predicted, and it became increasingly apparent that the importance of radar and radar countermeasures had become one of the major dictates not only of this war, but of any war in the future.

In reviewing options for lowering airframe RCS, industry and government offices began to narrow their focus to composite materials. The work conducted by Windecker under government contract now was reviewed with considerable urgency, and several additional small exploratory composite materials contracts under DARPA's aegis were let not only to Windecker, but other aerospace companies, as well.

Companies such as Northrop, Boeing, McDonnell Douglas, and Lockheed moved ahead with a number of studies during this period. Most of these were unmanned configurations built of fiberglass or other composite materials. Sizes varied from extremely small to aircraft with wingspans of up to 30 ft. Northrop purportedly assigned names such as *Manta* or *Hawk* to select members of the various configurations they developed.

While the new composite materials technology thrust rapidly gained momentum, the Air Force began assessing applications. Concurrently, though not as a result, work began on assembling a saleable program to develop a new heavy bomber. Though attempts to replace the aging Boeing B-52 *Stratofortress* had been made almost from the beginning of its production during the early 1950s, only the North American XB-70 *Valkyrie* had reached the hardware stage—and this bomber, though aesthetically one of the most beautiful aircraft ever, had proven to be an anachronism even before its first flight.

The demise of the XB-70, coupled with the failure of its Convair B-58 *Hustler* medium weight stablemate and the tremendous costs involved with both programs, had by the mid-1960s given the budget-generating U.S. Congress considerable food for thought. Accordingly, by 1965, when the Strategic Air Command tacitly stepped forward with its Advanced Manned Strategic Aircraft (AMSA) program—so acronymed to avoid the negative connotation associated with the word bomber—there appeared little chance it would ever reach the hardware stage.

AMSA, in fact, clung to life primarily because it was a relatively easy-to-fund study—and thus a program not requiring hardware development in the short term. Coupled with the decision by then-Secretary of Defense Robert McNamara to remove all bombers from SAC's inventory by June of 1971 that could not meet the requirement for low-altitude (terrain following) target penetration, it was considered a justifiable expense.

McNamara's decision, which essentially told the Air Force the manned, heavy, intercontinental bomber was an anachronism and thus redundant to future Department of Defense plans, bore considerable weight and had a significant long-term impact on SAC's history. In the meantime, a compromise bomber project, the interim General Dynamics FB-111A, suddenly surfaced to offset the effect of the disposal of hundreds of first-generation B-52As, B-52Bs, B-52Cs, B-52Ds, B-52Es, and B-52Fs. Though some 263 FB-111As initially were ordered, only 74 wound up in the inventory.

AMSA's (and the FB-111A's) fortunes changed at the end of 1968 with the election of President Richard Nixon. His new Secretary of Defense, Melvin Laird, was quick to remove all vestiges of McNamara's legacy and forge ahead with plans calling for the development of a new strategic bomber. By the late spring of 1970, the Air Force had been cleared to issue a contract to the winning AMSA contender, Rockwell International, and shortly afterwards work on the first B-1A (see Aerofax *Minigraph 24, Rockwell B-1A/B*) was initiated.

It is beyond the scope of this B-2 history to recount the B-1 story in detail, but suffice it to say

Complexity of blended surfaces on B-2A's under surfaces is slightly visible in this view of 82-1066 during the course of a test flight over Edwards AFB test range. Bomb bays are discernible.

that considerable controversy arose over funding when it became apparent it would be an out-of-date design even before consummation of its first flight.

The B-1's myriad technical problems, not the least of which was its faltering electronic warfare suite, had, by 1975, mortally wounded it. Coupled with the election of Jimmy Carter to the office of President and the still-unheralded advent of low-observables technology, the B-1's days were numbered.

Carter's administration ended speculation over the controversial B-1 during 1977 when it terminated the program after the completion of four prototypes. Air Force interest in the Rockwell bomber remained relatively strong, however, and support in Congress, though weak and of the "pork barrel" variety, continued unabated.

In the interim, the low-observables technology salient continued to grow with great rapidity. Studies under the aegis of various Department of Defense programs consistently touted its multi-disciplined approach to physically masking military hardware of all kinds. In particular, they strongly emphasized its applicability to aircraft.

B-1 program and hardware difficulties (which continue as of this writing), coupled with its extraordinary costs, soured public and Congressional support rapidly and eventually eliminated production following the completion of the one-hundredth aircraft. Paralleling the program's decline was the advent of the cruise missile which, ironically, started life as a B-1 adjunct weapon known as the ADM-86. Acronymed SCAD (Subsonic Cruise Armed Decoy) it became apparent its weapons delivery capabilities outweighed its decoy attributes. Most distressingly for B-1 advocates, the ADM-86, because of its innate "stand-off" launch capability, gave new life to the venerable SAC B-52 fleet.

Though the B-1 remained a viable acquisition option during this period, even following the Carter administration's seemingly successful attempt to kill it, new bomber studies continued to surface under various names such as *Saber Penetrator*. By 1975, it had become apparent that low-observables amounted to a new world of passive countermeasures. If incorporated in all forthcoming designs, all extant aircraft and other military equipment could be made out-of-date or ineffective in short order. Importantly, it became readily apparent the application of low-observables technology to new bomber designs would be absolutely mandatory if they were to remain capable of penetrating enemy defensive systems during the late 1980s and 1990s.

Quietly, and with little fanfare, the Carter administration began supporting the development of a new bomber, but not the Rockwell B-1. Instead, the Secretary of Defense and a small cadre of Air Force personnel began preparing requests calling for the development of a manned bomber that would incorporate an extensive low-observables package and be optimized to be as stealthy as possible.

With the 1980 election of Ronald Reagan as President, the inherited Carter administration's infant and almost unknown stealth bomber program and the on-going argument over whether the Rockwell B-1 should be reinstated in production, rapidly surfaced as primary administration funding goals. Reagan's Secretary of Defense, Caspar Weinberger, ambivalent about the need for two expensive bomber programs, quickly noted that Congressional support for bombers in general was not exceptionally strong—and that it would probably be necessary to minimalize B-1 production if it was to be achieved at all.

In consideration of this, on October 20, 1981, Weinberger announced the Reagan administration's "compromise" bomber decision. Rockwell's B-1 would be reinstated and placed in "small-scale" production in a more advanced form under the B-1B designation, and funding would be provided for initial development of the Advanced Technology Bomber (ATB). The contract for the latter, conceded on the same day to darkhorse contender Northrop and its sub-contract affiliates, Boeing and LTV, also was let and $7.3 billion for design, development, and the construction of one prototype was approved. A follow-on production program was expected to result in an order for as many as 132 ATBs with initial service entry to take place during the early to mid-1990s. The ATB, it was projected, eventually would replace the B-1B in the penetrator role.

The new B-1B was a compromise aircraft and not the strategic bomber the Air Force originally had envisioned. Incorporating interim low-observables technology in the form of improved fuselage/wing blending, increased use of composites, low RCS engine intakes, and an extensive DECM suite, it was an interim solution to what the Air Force claimed was a rapidly surfacing threat scenario that would render the B-52 fleet useless in the penetration role. And because this threat was so immediate, the development schedule of the ATB would not permit its use in the event of an all-out nuclear war.

Under the Carter administration, work on the

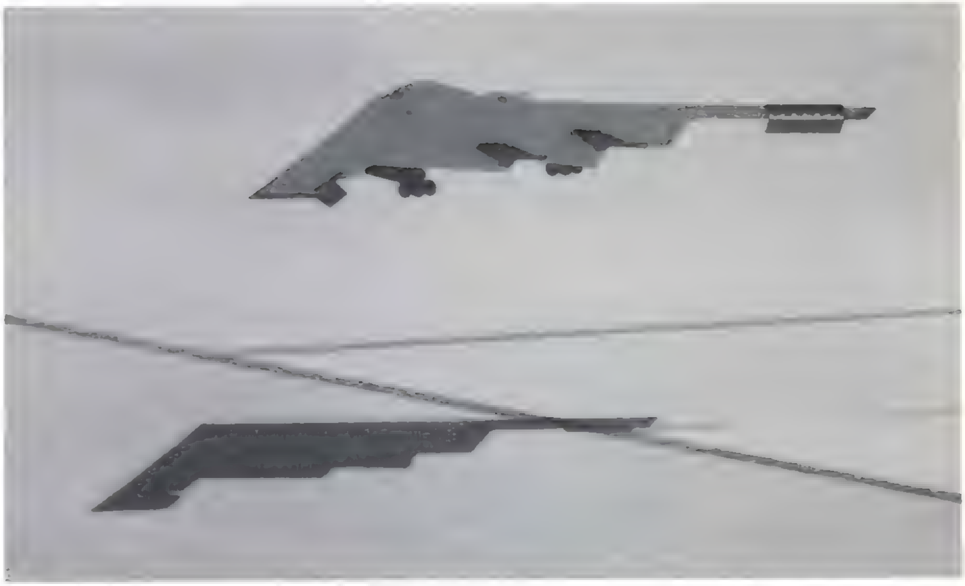
B-2A, 82-1066, during course of July 17, 1989 first flight between Palmdale and Edwards AFB. Landing gear were left extended throughout the 2 hour and 20 minute mission, as were the dorsally mounted auxiliary intake doors.

ATB had been initiated during the mid-1970s with preliminary studies calling for a bomber inegrating then-state-of-the-art low-observables technology. Design contenders were narrowed to two major teams during 1978, these consisting of consortiums led by Lockheed/Rockwell International and Northrop/Boeing/LTV. Consequent to this, both Pratt & Whitney and General Electric also began work on powerplants to meet the evolving bomber's propulsion needs.

Though thousands of planforms were examined by both teams, Northrop was quick to focus on the tailless or flying wing configuration. And though the company, under the auspices of its founder John Northrop, had long-ago acquired a reputation for promoting the attributes of such configurations, this background had little to do with the decision to make the flying wing the basis for its proposal.

The ATB requirement, generated by and managed from the Aeronautical Systems Division offices at Wright-Patterson AFB and emphasizing long range, high payload, and low observability, in fact had all but dictated the use of the flying wing or tailless configuration. Innately the most ideal of low-observables planforms, it offered minimal RCS and visual profiles, sufficient usable internal volume, span-loading structural efficiency, and high lift-to-drag for efficient cruise.

USAF



Landing of B-2A, 82-1066 at Edwards AFB. Drag rudders are approaching maximum extension angles, the "beaver tail" is providing slight nose down pitching moment, and the other elevons are inputting pitch control.

During 1979, Northrop engineer Hal Markarian, working with John Patierno and company low-observables authorities Irv Waaland and John Cashen, Ph.D., began the first ATB drawings under what soon would be referred to in-house as the N-14 Program. Within weeks of their initiation, a preliminary configuration had been settled upon, this superficially resembling what would become the actual aircraft, but differing in having a diamond-shaped-planform center section with an extremely small side-view cross-section. Contained in this would be four engines, a single large bomb bay, and of course, the cockpit and crew accommodations. Additionally, short wing panels extended off either side of the central diamond, these providing longitudinal stability, improved lift-to-drag characteristics, and the moment arm and control surface area required for pitch, roll, and yaw inputs.

Though initial studies were optimized for limited transonic performance, the latter later was determined superfluous. The wing leading edge sweep angle thus was chosen, like the airfoil section, to meet the more conservative high subsonic cruise speed directive. With fly-by-wire flight controls as a given, it also was decided to design the aircraft with neutral longitudinal (pitch) static stability, though with an innate nose-down pitching moment in the event of stall so that positive recovery could be accommodated.

Controlling the aircraft brought back nightmare-like memories of the original Northrop flying wing program—prior to the advent of computer-based fly-by-wire and fly-by-light flight control systems. The ATB, like its predecessors, would use a combination of elevon-like surfaces and "split drag rudders" to govern pitch, roll, and yaw stability, but unlike its predecessors, everything would be controlled by a complex computer-interfaced quadruple-redundant fly-by-wire flight control system designed to monitor the various actuators and surface positions and integrate their actions in real time with flight environment data. Flaps were considered but later rejected after computer analysis and simulations indicated a landing roll-out reduction of only 3%.

During 1983, approximately midway through the Northrop ATB design process, the Air Force asked the company to explore a revised mission profile that would require the bomber to operate in a low-altitude, terrain following mode. The original ATB requirement had been optimized for high-altitude target penetration scenarios, only, so the new Air Force request entailed a considerable reassessment of the original configuration.

The Air Force, according to Northrop test pilot Eric Hansen, asked for a trade study to determine the impact on the ATB design. They specified that the original high-altitude, takeoff (the aircraft was expected to be operable from any airfield capable of accommodating the ubiquitous Boeing 727), and fuel/payload capabilities be maintained—but that the aircraft be structurally adapted to accommodate the higher stresses of continuous low-altitude flight.

Northrop reviewed the various wing sweep, aspect ratio, and propulsion system options at their disposal and eventually concluded the existing design was most suitable. However, according to test pilot Hansen, an initial comprehensive analysis revealed that the interaction of the control center of pressure with the first bending characteristics of the wing structure resulted in wing bending loads under severe gust conditions that were larger than originally predicted. This aeroelastic effect could have been alleviated by structural stiffening, but a change in planform, moving the control center of pressure inboard of the structural node line, allowed much more efficient gust load suppression. Additionally, the cockpit was positioned farther forward and the engine intakes were moved aft as a result of bulkhead strengthening for the increased spanwise loading.

Consequent to the various changes was a major reconfiguration of the wing trailing edge configuration. The addition of a pair of inboard elevons on each wing-half resulted in a "double-W" profile that is seen on the aircraft as it exists today. Prior to that, the wing, when viewed from the top or underneath, had a single "W" trailing edge configuration. Besides providing the additional trailing edge area and moment arm required, the new configuration also reduced structural loading during "high-q" low altitude missions.

Additional changes resulting from this reconfiguration included a reduction in size of the "beaver tail" surface at the extreme aft end of the center section and a reconfiguration of the leading edge to improve pitch control at high angles of attack.

The redesign work entailed as a result of the Air Force request, which eventually became a mandated change, resulted in at least two years' delay in the program and cost an additional $1-billion. The ATB by this time had been declared "black" and placed under a veil of extreme secrecy, and as a result, expenses were easily masked in the highly classified black budget. It would not be until nearly eight years later that they would be permitted to surface, albeit with many constraints, in the public domain.

Concurrent with the work being taken on the basic design, Northrop created a number of autonomous laboratories under its corporate umbrella and under the auspices of select subcontractors. These were set-up to conduct full-scale hardware and software testing relating to virtually all aircraft systems and subsystems. Propulsion and control system work was (and continues to be) conducted at Edwards AFB; the environmental control system was run through an extensive test program at Northrop; a B-2 avionics integration laboratory was built; and Boeing developed full-scale systems for testing the aircraft's landing gear and fuel systems. Additionally, flight simulators were built and eventually, over 12,000 hours of simulator time were accumulated by company and Air Force pilots.

By the time of the Pentagon's preliminary program design review, the major changes dictated during 1983 had been incorporated and construction of the first aircraft was underway. On November 19, 1987, the Air Force quietly appropriated $2 billion for initial production of the ATB and consequently formally designated it B-2. Shortly afterwards, work got underway on the first four production aircraft.

Because of the size of the B-2, its potential production program, and the unique technology utilized in its manufacture, the Air Force agreed to appropriate funding for the construction of new production, maintenance, and support facilities at Palmdale, California (operated by Northrop) and Edwards AFB, California (operated by the Air Force). These were rushed to completion starting in 1985, along with numerous smaller facilities at subcontractors such as LTV at Grand Prairie, TX and Boeing at Wichita, Kansas.

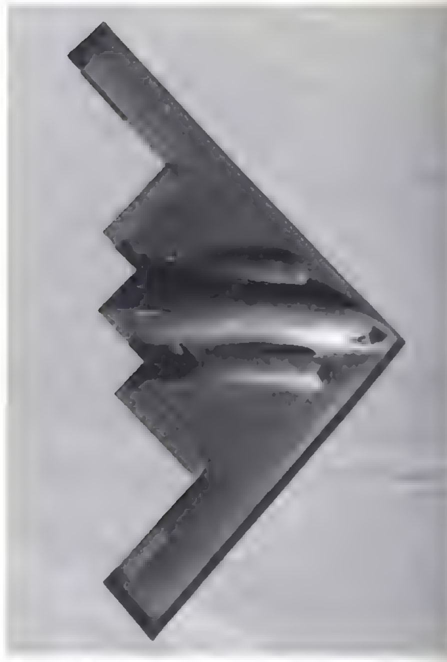
In the interim, Northrop continued an extensive research program that eventually would span some seven years and result in 24,000 hours of wind tunnel model testing; 16,000 hours of

Northrop

B-2A control surface hinge seals are optimized to accommodate both RCS and aerodynamic concerns.

USAF

Slight bulges are visible where the four engine bays and the two bomb bays are located.



Northrop

Engines are recessed well forward of the wing trailing edge in order to lower hot exhaust exposure.

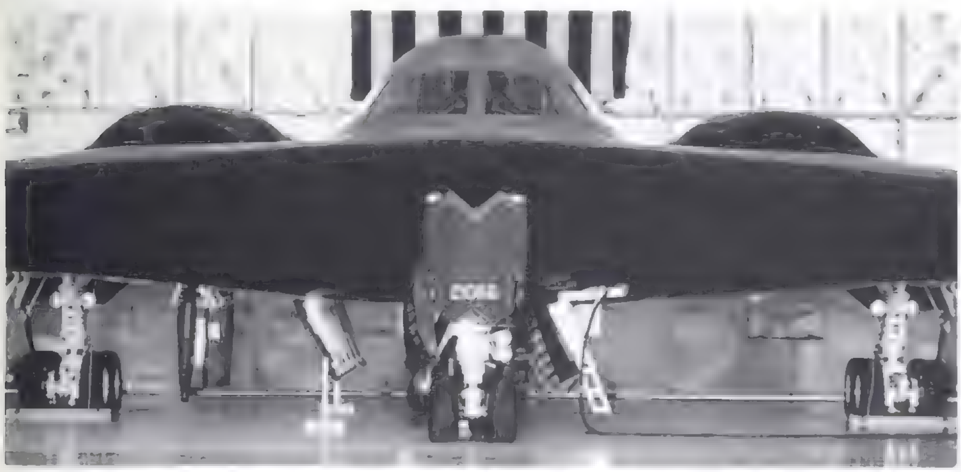
engineering simulation; and 6,000 hours of control system tests. The latter were conducted on a full-scale static unit equipped with a full hydraulic actuator complement and a flight control bench.

Perhaps most importantly, due to the complexity of the B-2's highly blended aerodynamic shell, its use of advanced materials, and the exigencies of low-observables technology, Northrop installed and utilized an extremely advanced computer aided design and manufacturing (CAD/CAM) system at its B-2 Division (Integrated Composites Center) facility at Pico Rivera[1], California at a cost of more than $1 billion. With it, the aircraft's external configuration and the related positioning of every internal component was maintained on a 3-dimensional database that was interfaced with the production machine tooling, the various robotic systems, the design tooling, and the associated tooling alignment requirements. This database was shared electronically with Boeing Military Airplanes in Wichita, Kansas, LTV Aerospace in Grand Prairie, Texas, the Air Force, and whenever necessary, other miscellaneous subcontractors. It reduced required numeric-control programming time approximately 40% from that needed by conventional systems. Accuracy also made possible a 97% success rate (versus traditional rates of 60%) on the first installation of tubing, fluid systems, and mechanical systems.

Northrop's 3-dimensional system contained a common data base that retained information pertaining to literally every facet of the aircraft's design and materials—including such diverse items as rivets, wire harnesses, hydraulic lines, and other minutiae. This data base, because of its size, intricacy, associated computational power, and over-all eclectic content virtually eliminated the need for master tooling; permitted an interfacing of effort by the various contractor and subcontractor departments; decreased part fitting times; reduced the amount of time required to create numerically controlled machining programs; generated considerable time and cost savings as a result of tube cutting accuracies; permitted the formulation of planning documents from engineering drawings; and interfaced the development of technical manuals and the data used by miscellaneous departments and subcontractors.

By late 1989, Northrop had contracted with 131 sub-contractors, Boeing had contracted with 69, General Electric—the engine manufacturer—had contracted with 52, and LTV had contracted with 32. Among the more significant of these were the following: AAI Corp.; Abex Corp.; Adage, Inc.; Adams-Russell Co.; Adams-Russell Electronics Co.; AiResearch Division of Allied Signal Aerospace; Allied Corp. Bendix Flight Systems; Allied Signal Aerospace; Allied Signal Fluid Systems Div.; Amaco Performance Products; Amdahl Federal Service Corp.; Applied Consulting & Tech Service; Associate N/C Programming; Arkwin Industries, Inc.; B&H Assoc.; B & M Assoc.; Battelle Columbus; Belcan Services; Bell Systems Engineering; BDM Corp.; Boeing Military Advanced Systems Co.; Boeing Military Airplane Co.; Burns & Roe Pacific Engineers; Butler Service Group; CAE-Link Corp.; Collins Defense Communications; Condor Systems, Inc.; Consultants & Designers, Inc.; Continental Microwave & Tool Co.; Contract Services; Defense Systems; Defense Technologies, Inc.; Deliotte, Haskins &

[1] Pico Rivera, opened during 1981, originally was an old Ford assembly plant for automobiles.



Jay Miller/Aerofax, Inc

Deepest section of fuselage accommodates bomb bays. Two bomb bays are provided, with one located on either side of the aircraft centerline. Each bomb bay is equipped with two doors. Right bomb bay outer door is visible.

USAF

All receiving and transmitting antennas are completely faired within the aircraft's aerodynamic shell.

USAF

B-2A is extremely clean from an aerodynamic standpoint. Blending of all surfaces is perhaps the most successful of any aircraft built to date.

USAF

Engine exhaust slots are recessed and channeled in order to reduce exposure to heat seeking sensors and weapons. Exhaust plume development also has been minimized.

USAF

B-2A inflight refueling trials utilized McDonnell Douglas KC-10A, 79-1951. Trailing formation runs were followed by actual fuel transferral on November 8, 1989.

USAF

Compatibility with the Boeing KC-135A as an inflight refueling tanker was confirmed utilizing NKC-135E, 55-3135, during tests conducted over the Pacific Ocean.

Sells; Digital Equipment; E-Systems; Eastman Kodak; Eldec Corp.; Electrodynamics, Inc.; Electromagnetic Devices; Ensign Bickford Co.; Ernst & Whinney; Evolving Technology; Ewing Technical Design, Inc.; Facilities Systems Engineering; Fairchild Communications and Electronics Co.; Fenwal, Inc.; Frequency West; Fairchild Communications & Electronics Co.; Garrett Auxiliary Power, Inc.; GEC Astronics Corp.; General Devices, Inc.; General Dynamics Electronics Division; General Electric; General Electric Aircraft Controls; General Electric Aircraft Engineering Group; General Electric Aircraft Equipment Div.; Gould Defense Systems; Gull, Inc.; H. L. Yoh; Hamilton Standard; Hazeltine; Hercules Aerospace; Hercules, Inc.; Hi Tec; Honeywell, Inc.; Hughes Aircraft Radar System Group; Hughes Electronics Dynamics; Hughes Training & Control Div.; Inconen Corp.; International Business Machines; Interglobal Technical Services; ITT Gilfillan; Jaycor; Kaman Avidyne; Kaman Instrumentation; Kaman Sciences Corp.; Kaymar; Kearfott Guidance/Navigation Corp.; Keco Industries, Inc.; Kirk-Mayer, Inc.; Kom Wave Corp.; Lighting Technologies; Lockheed Aircraft Corp.; Lockheed Electronics, Inc.; Logicon; Los Alamos Technical Assoc., Inc.; LTV Aircraft Products Group; LTV Missiles & Electronics Group; Mantech; Mantech International Corp.; Mantech Support Technologies, Inc.; McDonnell Douglas Aircraft Co.; McKenna, Conner & Cuneo; Microdynamics, Inc.; Micro Lab; Microwave Associates, Inc.; Microwave Development Labs; Microwave Engineering Corp.; Miltope Co.; Mini Systems; Mini-Systems Associates; Moog, Inc.; Multax Systems; Narda Microwave, Inc.; N/C Services; Nelson, Coulson & Associates, Inc.; Norman Engineering Co.; OEA, Inc.; Parker-Hannifan Corp.; PDA Engineering; PDS-Tech Services; Pollack & Son; Raychem Corp.; Raytheon Corp.; Resdel Engineering Corp.; RHO Co.; Rockwell International Corp.; Rosemount, Inc.; Sanders Associates, Inc.; Science & Engineering Assoc.; Scipar, Inc.; Servicon Systems, Inc.; Simmonds Precision; Smith Industries Aerospace & Defense; Spectragraphic Corp.; Standard Manufacturing Co.; Stonehouse Group; Storage Tech Corp.; Sundstrand Corp.; Superior Design Co.; Superior Manufacturing Co.; TAD Technical Services Corp.; Tech Resources, Inc.; Tech Systems Corp.; Teledyne Electronics; Teledyne McCormick; Texas Instruments Ridgecrest; Transportable Technology, Inc.; TRW Redondo Beach; TRW Oklahoma Engineering Office; TRW Sacramento Engineering Office; TRW Sapce & Defense; Unisys Corp., Defense Systems Group; United Aircraft Products, Inc.; United Technologies; UTS Engineering Consultants; Vaga Industries; Vanite Industries; Varian; Verac, Inc.; Versatec; VTC Service Corp.; Vickers, Inc.; Wang; Watkins-Johnson Co.; Whittaker Corp.; and Xerox.

The manufacture of the B-2's major components was equally divided between Northrop (12,000 employees assigned), Boeing Military Airplanes (10,000 employees assigned), and LTV Aerospace (4,000 employees assigned). Northrop manufactured the forward center section with cockpit; Boeing produced the aft center section, the outboard wing sections, the fuel system, the weapons delivery system, and the landing gear; and LTV was responsible for the intermediate fuselage sections, the aluminum and titanium structural components, and the composite parts.

Among the approximately 900 new materials and processes developed to accommodate the B-2's advanced technology and systems was LTV's development of one of the world's largest computer-controlled robotic units. Optimized for automated drilling and fastening of composite/metallic aerostructures, this five-axis device performed the drilling and fastening of large, highly-contoured aircraft parts requiring the combining of composite materials with titanium or aluminum substructures.

Concurrent with work on the actual airframe design and construction, peripheral elements such as propulsion system testing, navigation and weapons system design and testing, and development of the electronic warfare suitealso were undertaken. Electronics related assemblies, including navigation and bombing equipment, were flight tested aboard a specially modified Air Force Systems Command Boeing C-135A, 60-0377 (radar systems, including those manufactured by Hughes, were tested during the course of 305 C-135 missions; during these flights, more than 1,000 hours were devoted specifically to radar work and 650 hours to navigation system testing); and the winner of the powerplant competition, General Electric's F118 turbofan, was tested aboard specially-equipped Boeing C-135A, 55-3122.

As originally scheduled, the first six B-2's, by now being more formally referred to as B-2As, were slated to serve as test or prototype aircraft. Additionally, two airframes were set aside for structural testing, with at least one of these being shipped to LTV's Grand Prairie, TX facility for

Northrop

McDonnell Douglas KC-10A and Northrop B-2A represent two technology extremes in today's Air Force. KC-10A is built almost totally of metal alloys and B-2A is built almost totally of plastic-like composites.

life-cycle work and other structural considerations. When reviewing operational requirements, it was decided that five of the flight test aircraft (the exception being the second airframe) eventually would be recycled through a mod and upgrade program in order to bring them up to full operational standard. They then would be integrated into the operational Air Force inventory.

The original Air Force requirement for 133 B-2As (including the prototype), by 1990, had been pared to 75 aircraft as a result of FY 1991 budget cuts. It now appears doubtful that even this relatively small production run will be consummated.

Because of the extraordinary cost of the B-2 and what now is viewed as a massive down-grading of the U.S.'s primary military threat, funding for the program—amounting to some $7 to $8 billion per year over the next five years—has been difficult for the Air Force to justify. Congressional concerns which bring into play diverse political and socio-economic elements have dictated a sporadic funding situation that to date, has not given Northrop and its various sub-contractors any assurance the aircraft eventually will be placed in full-scale production. Orders for the B-2 have come in minuscule lots, with three B-2As being funded during FY 1989 and two more being funded during FY 1990. To date, fifteen aircraft have been confirmed under contract, these including six flight test and nine production examples. Two static test articles also have been manufactured.

Compounding the funding difficulty has been what many observers consider an untenable rise in unit production cost. The latter originally was estimated to be $274 million (1989 dollars) based on a buy of 132 aircraft. This figure, one year later, had increased to $530 million per aircraft, and as of this writing, now is expected to be in excess of $864 million based on a limited buy of 17 aircraft. In fact, if the latter buy holds true, unit costs potentially could reach figures in excess of $1.5 billion—making the B-2A, by far, the most expensive military aircraft in world history. During May of 1991, in what appeared to many observers to be an unfavorable portent for the future, the House Armed Services Committee voted to zero the Air Force's Fiscal Year 1992 procurement request of $3.2 billion for four more B-2As. A total of $1.56 billion was allocated, however, for continued development and it is expected that the Senate will support the House-denied $3.2 billion request.

Defending the aircraft, in consideration of it's exorbitant cost, has been difficult both for the Air Force and Northrop. Though flight tests appear to be going reasonably well, and though the aircraft appears to be as stealthy as promised, the decline of the primary Soviet threat has made justification of the B-2 as a weapon and as a financial burden an item of extraordinary contention.

To offset the arguments swirling around the ongoing deflation of the B-2's primary target, during the late spring of 1991, the Air Force initiated a new tactic that underscores the aircraft's potential in non-nuclear, conventional weapons delivery modes. The Gulf War, wherein targets apparently were destroyed with relative impunity by the Lockheed F-117A, was used with considerable fervor by B-2 proponents as an example of just how effective low-observables technology really is. One of the more memorable quotes pertaining to this came from Lt. Gen. Charles Horner during a post-war House Appropriations Defense Subcommittee session. "The B-2 can carry over 10 times the load of an F-117 at over five times the unrefueled range. Put another way, the B-2 combines the range and payload of the B-52 with the advantages of the stealth F-117 that proved so valuable in Desert Storm. Would I have used a B-2 in Desert Storm? You bet I would."

The prototype Northrop B-2A, 82-1066, was completed on production standard tooling during early November of 1988 and officially rolled out on the 22nd of the month during an invited-guests-only gathering at Air Force Plant 42, Palmdale, California. The first taxi test was prematurely terminated on July 10 when the right inboard engine (No. 3) ingested debris through one of its auxiliary inlet doors and was damaged. Interestingly, special attention had been paid to the potential problem of foreign object ingestion and for days prior to the initiation of taxi tests, teams of 30 to 40 Northrop employees could be seen walking the 12,000 ft. main Palmdale runway checking for potentially damaging debris.

Following repairs, this aircraft, after completing the scheduled 4 hours of miscellaneous high-power static engine and high-speed taxi tests on July 13, while crewed by Northrop chief test pilot Bruce J. Hinds in the left seat and Air Force Col. Richard Couch in the right, at 6:36 a.m. on July 17, 1989, began rolling down the main Palmdale runway on what was to be the beginning of its first flight. Approximately 22 seconds into the takeoff roll, the aircraft main gear cleared the ground. Flying east from Palmdale, it landed at Edwards AFB at 8:29 a.m., some 2 hours and 20 minutes after departure. Maximum speed attained on this flight was 190 kt. and maximum altitude was 10,000 ft. (this data was obtained via a temporary trailing wire device which provided static air pressure data for airspeed, altitude, and miscellaneous other calibration requirements). Two General Dynamics F-16s flew chase.

Almost exactly one month later, on August 16, following postponements on August 12 and 15, a second flight was undertaken, this marking the beginning of the first stage of Block 1 (aerodynamic performance and airworthiness) flight testing eventually scheduled to consume 75 hours and require 15 flights. This flight, wherein the landing gear were cycled for the first time, eventually was cut short after a low oil pressure reading indicated lubricating problems with one of the aircraft's airframe—mounted accessory drives (AMADs; the fourth flight, on September 21, similarly was cut short). A third flight, lasting 4 hours and 36 minutes, was successfully undertaken on August 26, this resulting in a maximum altitude achieved of 25,000 ft. and a maximum airspeed achieved of 300 kt. This flight also served to explore inflight refueling compatibility when a McDonnell Douglas KC-10A, 79-1951, from March AFB, California was used to practice technique without actually transferring fuel. Additionally, bank angles of up to 60° were recorded. A fifth flight, introducing Lt. Col. John Small to the B-2 and exploring more of the low-speed flight envelope, took place on September 23.

Successfully accomplished during the 7th B-2A flight, lasting 6 hours and 5 minutes on November 8, 1989 was the first real inflight refueling—conducted with the March AFB KC-10A. This took place approximately three hours after takeoff, with the B-2A successfully making contact and eventually taking on a total of 40,000 lb of JP-8 fuel.

Block 2 flight trials exploring the aircraft's low-observables characteristics now were brought into the mission envelope and the aircraft was programmed for a five-month down period so that low-observables-related upgrades could be incorporated. Block 1 testing, verifying basic flight-worthiness of the B-2A, consequently was completed during June of 1990.

Test pilot Hinds has, on occasion, described the B-2A's flight characteristics as extremely favorable. He considers the bomber's stick forces to be light and its over-all controllability to be exceptionally responsive, particularly for a large aircraft. He claims also that acceleration is extraordinary for an aircraft of the B-2A's size. Landing sink rates routinely are 1 ft./sec. or less and touchdowns, usually occurring at 140 kt. for average weights, are unusually smooth.

As of this writing, three B-2As have flown and a fourth is scheduled to follow, shortly. Aircraft number 2, 82-1067, heavily instrumented for loads test work, took to the air from Palmdale on October 19, 1990, and flew to Edwards on the same day, and aircraft number 3, 82-1068, also flew from Palmdale, arriving at Edwards on June 18, 1991.

The latter flight was prematurely terminated following a landing gear retraction and extension difficulty approximately 1 hour into the flight. The aircraft made a precautionary landing on Rogers Dry Lake on the Edwards AFB complex.

The number 3 B-2A apparently is the first to be equipped with an active electronic countermeasures suite and other defensive capabilities, and its flight and system test program is considered particular critical to forthcoming budgetary issues. This aircraft will be used for avionics and weapon-system integration and also will participate actively in the B-2 Block 2 low-observables test program. The latter will account for some 25% of the planned 3,600 test hours.

A breakdown of prototype B-2A assignments is as follows:

AV-1 (82-1066)—flight envelope expansion (to be shared with AV-2) and initial low-observables testing.

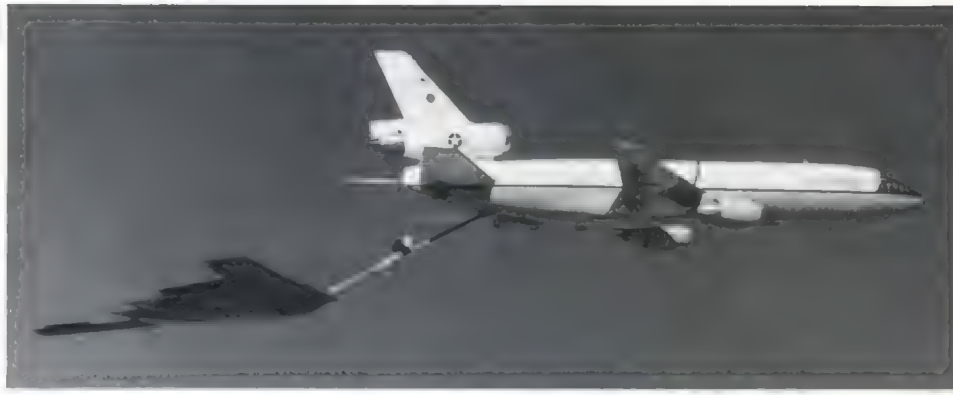
AV-2 (82-1067)—loads and performance testing (to be shared with AV-1) and initial weapons separation testing.

AV-3 (82-1068)—avionics suite testing (to be shared with AV-4), some low-observables testing, and miscellaneous weapons compatibility testing.

AV-4 (82-1069)—avionics suite testing (to be shared with AV-3), some low-observables testing, and miscellaneous weapons compatibility testing.

AV-5 (82-1070)—climatic testing at Eglin AFB, Florida and miscellaneous weapons compatibility testing.

AV-6 (82-1071)—technical order validation/verification, operational test and evaluation programs, and low-observables testing.



USAF

Initial refueling trials called for the B-2A to fly in tandem formation with McDonnell Douglas KC-10A. Boom contact was not made. B-2A, however, since has proven docile in receiver role.

USAF

Due to placement of B-2A receiver receptacle, visual and radio communication are necessary in order to bring the B-2A into the tanker's boom maneuver envelope.

At a slightly later date, two of these aircraft will be set aside to be used as Air Force maintenance evaluation trainers, with Northrop personnel continuing to maintain and operate the test instrumentation complements.

The flight test program taking place at Edwards AFB under the aegis of the B-2 Combined Test Force is averaging approximately 30 flight hours per month as of this writing. Seven test pilots have become B-2A qualified and an eighth will join this team by the end of the summer of 1991.

By May 2, 1991, the B-2A flight test program had accomplished the following:

(1) Demonstrated the aircraft's flight characteristics in more than half of the total operational envelope.

(2) Verified the accuracy and performance of the air data system and avionics display systems.

(3) Demonstrated the aircraft's handling qualities including yaw, pitch, and roll maneuvers as well as level turns, and wind-up turns at bank angles of up to 60°.

(4) Demonstrated its compatibility with KC-10 and KC-135 tankers during numerous aerial refuelings.

(5) Completed a series of engine air starts and throttling tests with no anomalies.

(6) Reached a maximum altitude of 45,000 ft.

(7) Attained a maximum speed of approximately 400 kts.

(8) Demonstrated excellent early aircraft reliability and maturity.

Other highlights to May 2, 1991 include:

(1) Longest flight to date: 7 hrs. 23 min. during flight #10 on May 3, 1990.

(2) Most flights in one week: 4 flights in 4 days during a period from April 2 thru April 5, 1991.

(3) The Air Force Association awarded the B-2 test team its prestigious Theodore von Karman Award for most outstanding contribution in the field of science and engineering during September of 1990.

(4) Test pilots Bruce Hinds (Northrop) and Col. Rick Couch were given the Society of Experimental Test Pilots' Iven C. Kincheloe Award for outstanding performance in flight testing.

Northrop has noted, too, that manufacturing hours per aircraft already have been reduced considerably. AV-1 is stated to have taken nearly 3.5 million manufacturing hours to complete, whereas AV-2 took 1.75 million hours. It is estimated that over the first eleven aircraft, the number of manufacturing hours will drop to approximately 1 million per aircraft.

It has been stated the current flight test program will permit 80% of the B-2A's total flight envelope to have been explored during its first six months. During the first two years, the entire flight envelope will have been explored, 90% of the propulsion system test program will have been completed, 70% of the radar signature testing program will have been completed, and the flight load envelope will have been explored.

If and when the B-2A enters the operational Air Force inventory, it is scheduled first to be assigned to Whiteman AFB, Missouri (located approximately 45 mi. southeast of Kansas City, it is considered less vulnerable to attack because of its central-U.S. location). Under an $84.8 million contract consummated in the FY 1988 budget, thirty-four special hangars, additional maintenance docks, a new maintenance control complex, a mission operations center, a radar approach control facility, and an aircraft support equipment and parts storage facility are being built under the aegis of the 509th Bomb Wing. The special hangars will be designed to protect the aircraft's relatively fragile external materials and configuration from environmental variables. Whiteman initially is expected to be used for B-2 aircrew and maintenance crew training.

A second base for a second contingent of B-2s will be revealed if and when funding for sufficient aircraft is approved. It has been stated, however, that the B-2A can reach any target on the globe from three base locations: Whiteman AFB, Diego Garcia in the Indian Ocean, and Guam.

As work on the B-2A continues in order to bring it to operational status, a curriculum for training B-2 crew members currently is under development by Northrop and the Air Force. At this time, two 5 hour B-2 missions per month will be required to maintain currency in the aircraft, and these will be complemented by six flights as pilot-in-command in a Northrop T-38 trainer. An additional six missions per year will be necessary to maintain instrument flight currency. Integrated into this curriculum, five B-2 weapon system trainer flights in the special Link Flight Simulation Division trainer will be required.

Concurrent with the activity at Whiteman, the Oklahoma City Air Logistics Center at Tinker AFB, Oklahoma has been chosen as the primary B-2A depot facility. It will be complemented by related efforts at Ogden Air Logistics Center at Hill AFB, Utah; Sacramento Air Logistics Center at Sacramento, California; San Antonio Air Logistics Center at San Antonio, Texas; and Warner-Robins Air Logistics Center at Robins AFB, Georgia.

The flight test program through mid-1991, under the aegis of the B-2 Combined Test Force at Edwards AFB, California, had logged approximately 225 hours of flight time on the three flying aircraft during the course of approximately sixty flights. Company test pilot Hansen notes the aircraft has

Northrop

Four **B-2As**, presumably **82-1066, 82-1067, 82-1068,** and **82-1069** are seen on the line at Northrop's Palmdale, California production facility. Noteworthy is the coloring of the composite materials skin prior to application of radar attenuating paint, extensive use of protective covering during manufacturing process, and special cotton shoes worn by personnel.

Northrop

Presumably the first **B-2A, 82-1066,** shortly before completion and roll-out, at Northrop's Palmdale, California production facility. Aircraft is draped in protective plastic and rubber matting material. The latter serves as walkways for personnel on the aircraft's upper surface. White paint is thought to be base coating to which radar absorbent paint is applied.

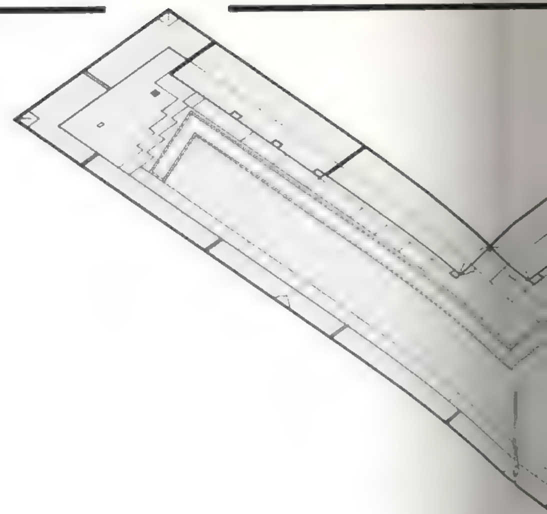
USAF

Overhead view of **B-2A, 82-1066**, during early test flight. Aircraft still mounts trailing wire static calibration unit. In this view, the latter is extended and in fact trails out behind the aircraft out of the left edge of the picture. Leading edge and wingtip RAM provide distinctive black trim. "W" shaped trailing edge is particularly noticeable from this angle.

NORTHROP B-2A, 82-1066

COLOR AND MARKINGS:

The Northrop B-2 aircraft that have been completed to date all have been painted in special, low-observables paint that is chemically and physically optimized for radar attenuation. The color is a dull blue-black with an approximate F.S. equivalent of 36081. "Do Not Walk" areas are marked by lighter grey/grey-white lines that have an approximate F.S. equivalent of 36495. This paint, too, is designed to attenuate radar energy. Other markings area applied in low-visibility paint that is chemically in tune with low reflectivity throughout the elctromagnetic spectrum. Prototype B-2As currently carry a serial number on the aft fuselage, national insigne, various small warning and maintenance stencils, and the badges of Strategic Air Command, Air Force Systems Command and Air Logistics Command.

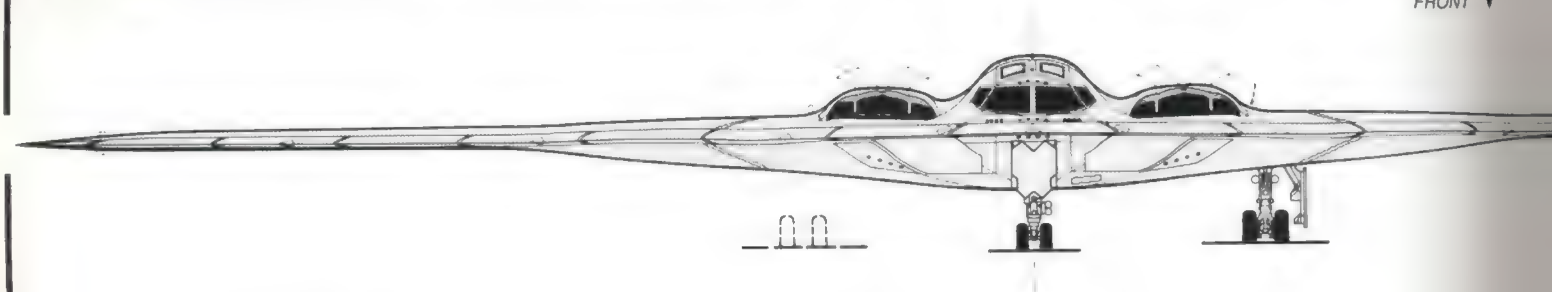


PERFORMANCE AND SPECIFICATIONS:

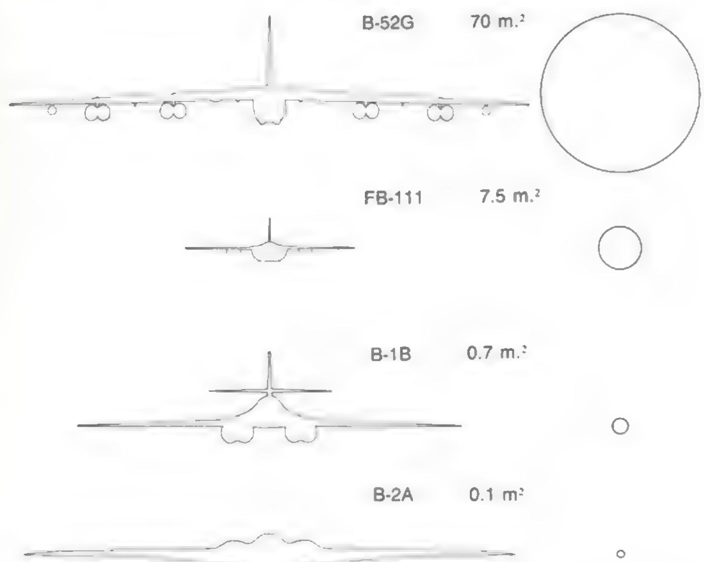
Height: 17 ft. 0 in. (5.18 m.)
Height to nose tip: 10 ft. 0 in. (3.04 m.)
Height to wing tip trailing edge: 9 ft. 0 in. (2.74 m.)
Length: 69 ft. 0 in. (21.03 m.)
Wingspan: 172 ft. 6 in. (52.59 m.)
Wing area: approx. 5,100 ft.^{2} (464.5 m.^{2})
Wheel track: 40 ft. (12.20 m.)
Crew accommodations: 2 with provisions for 3
Empty weight: approx. 125,000 lb. (56,699.6 kg.)
Gross takeoff weight: 371,330 lb. (168,434.18 kg.)
Landing approach speed: 161 mph (259 km/h)
Service ceiling: 50,000 ft. (15,240 m.)
Range: 6,600 n. mi. (12,230 km.) unrefueled w/24,000 lb. (10,886 kg.) weapon load (high-altitude mission)
4,400 n. mi. (8,153 km.) w/37,300 lb. (16,919 kg.) weapon load ("high-low-high" mission)
10,800 n. mi. (18,532 km.) w/single refueling

TOP ▲

FRONT ▼

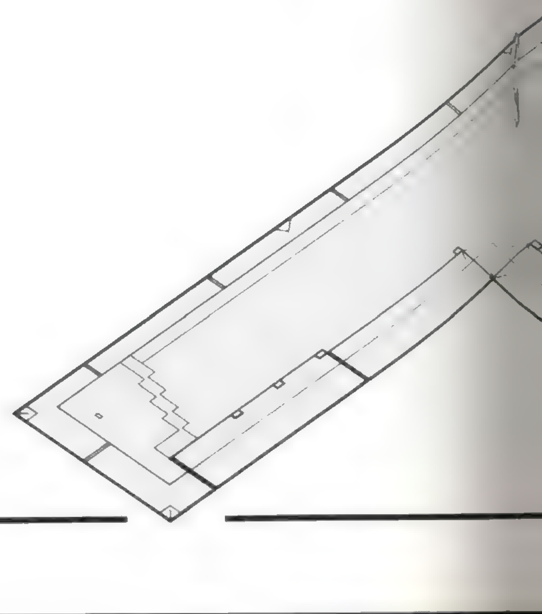


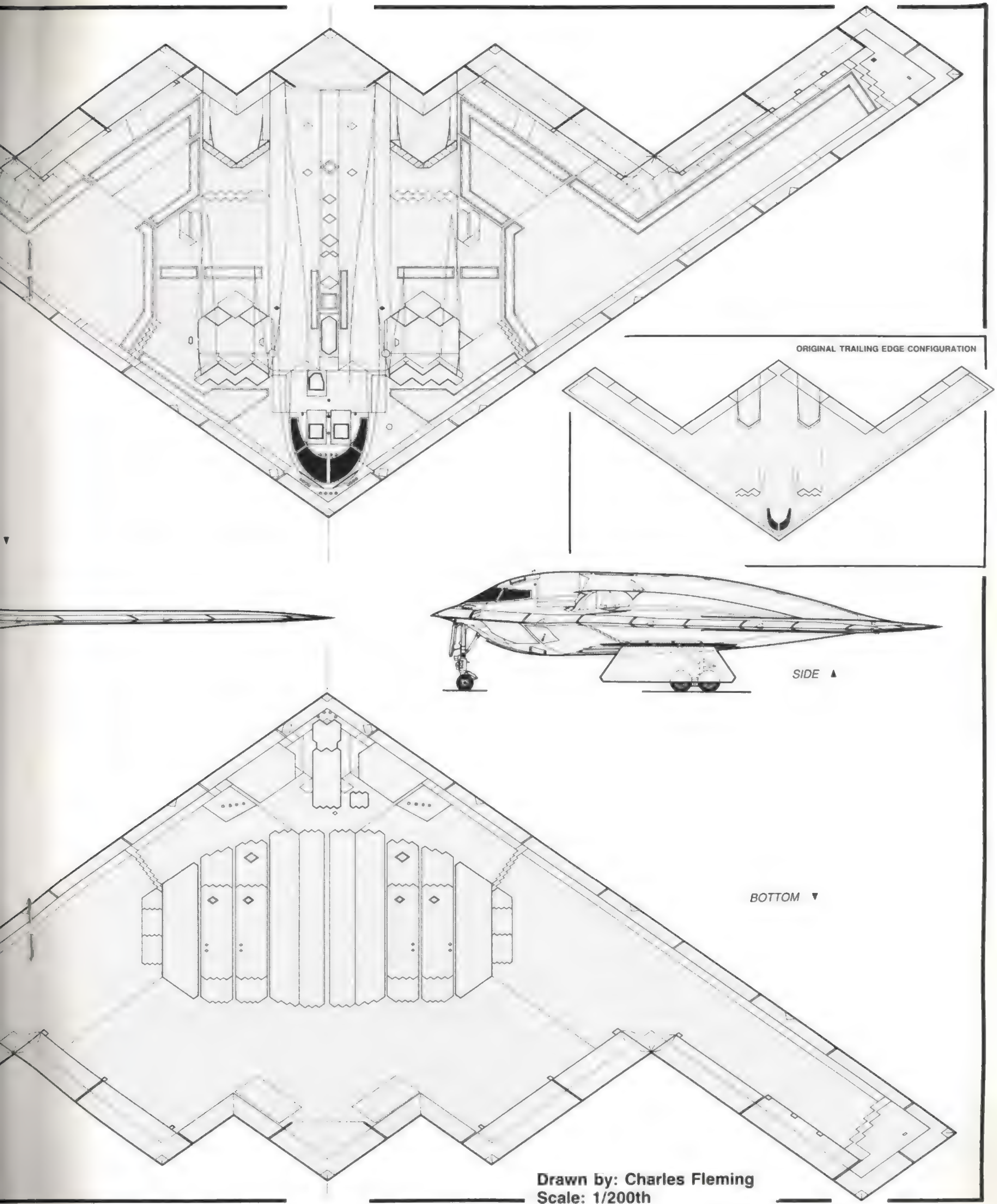
COMPARISON OF RADAR CROSS SECTION:



AVAILABLE SCALE MODELS:

1/200	DML
1/72	Testors





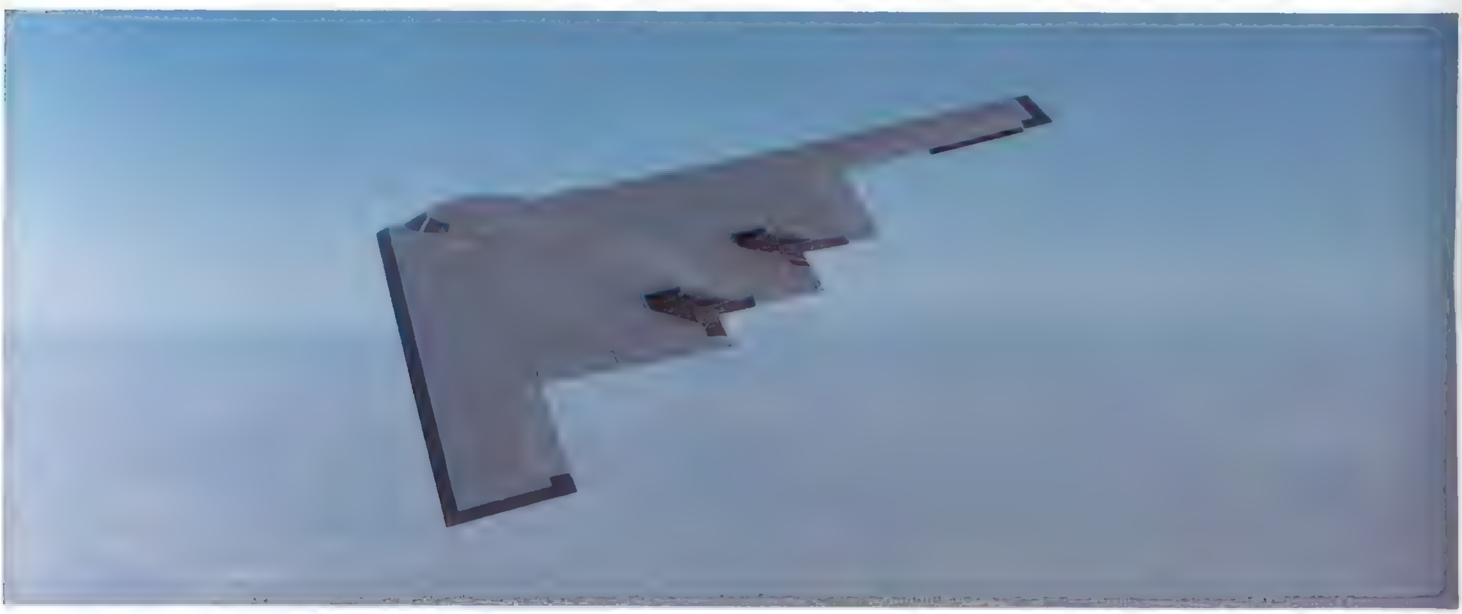
Drawn by: Charles Fleming
Scale: 1/200th

USAF

Though extremely rigid when compared to conventional all-metal aircraft, the B-2A's structure nevertheless does flex. Close examination of this image indicates an upward twisting of the outer wing panels while the aircraft is in low-speed cruising flight. Note the slightly open position of the drag rudders and the faired position of all other control surfaces.

Jay Miller/Aerofax, Inc.

*Both Lockheed **F-117A, 825,** and Northrop **B-2A, 82-1066,** were displayed publicly during a special "Stealth Week" at Andrews AFB, Maryland, during June of 1991. This event was a rather poorly disguised lobbying effort on behalf of the Air Force to generate Congressional support for the beleagured stealth bomber program. Also displayed was Lockheed YF-22A, N22YF.*



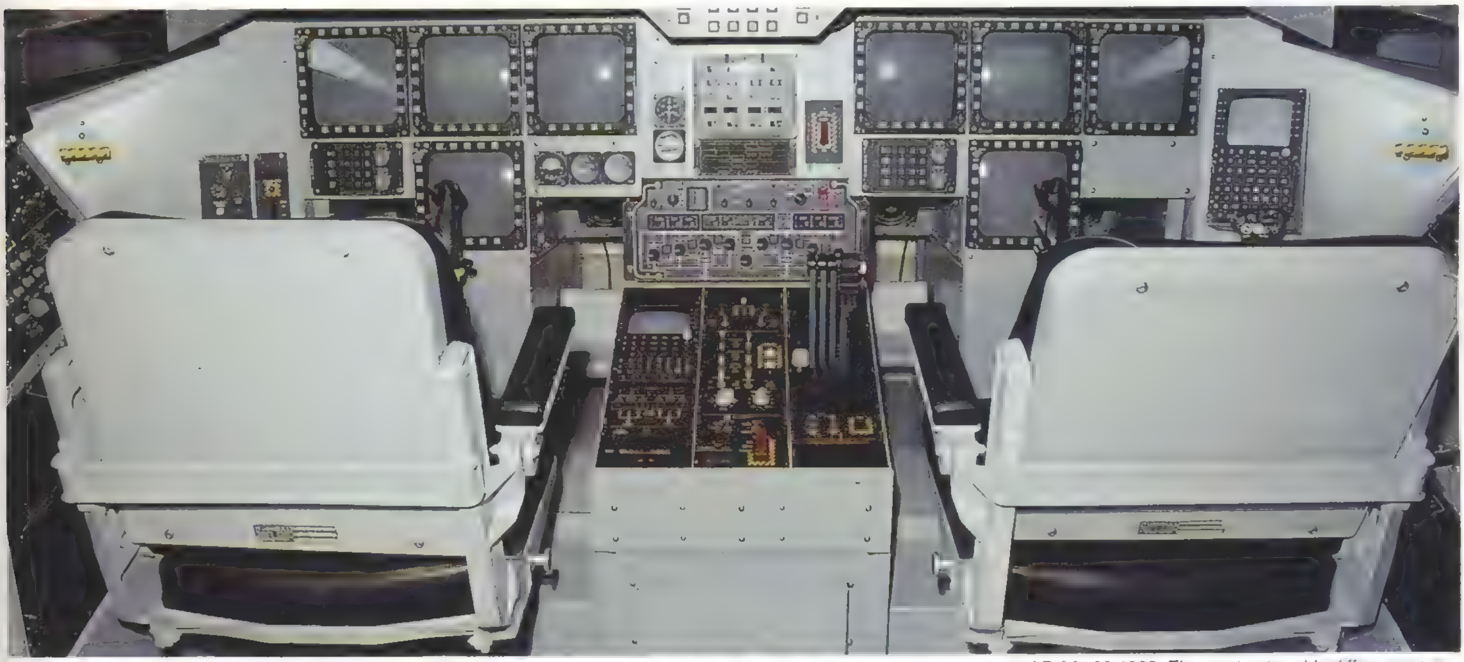
Air Force

***B-2A, 82-1066,** over the Edwards AFB, California test range. Straight leading edge is readily apparent as are severely recessed exhaust nozzles. Aircraft is completely covered with radar abosorbent paint and low-visibility markings. With exception of exhaust channel paneling, virtually all of the wing trailing edge consists of articulated control surfaces.*

Northrop

B-2A, 82-1066, *main instrument panel. Though controls, including stick and rudder pedals are strictly conventional, all other aspects of cockpit are state-of-the-art. Primary flight and system information presentation is via multi-screen multi-function display system. Some analogue instruments remain for emergency back-up.*

Jay Miller/Aerofax, Inc



B-2A *static simulator emulates the actual—less complicated—production* **B-2A** *cockpit and differs significantly from the cockpit of* **B-2A, 82-1066.** *The most noticeable difference is in the number of cathode ray tube displays (multi-function displays). Whereas* **B-2A, 82-1066,** *has only three for each crew member, the simulator is equipped with four.*

The B-2A's pilot has no visual clue, other than light indicators under tanker belly, as to where to position his aircraft during the refueling process. Rotating receiver assembly is mounted well aft of cockpit.

met or exceeded all expectations relating to aerodynamic performance characteristics, including drag and fuel-flow. Additionally, he has stated the longitudinal stability levels have been higher than predicted and control effectiveness levels also are higher, "resulting in faster roll performance". The only unexpected anomalies to date that have surfaced in the public domain include a slight pitch oscillation in low-level flight, and differential heating in the "aft-deck" area near the engine exhausts.

During March, April, and May of 1991, only thirteen flights, logging some 54 hours, were successfully completed. The first two aircraft, AV-1 and AV-2, had been constrained from higher availability rates because of modifications bringing the number 1 aircraft on-line for initial low-observables tests, and problems with the number 2 aircraft's bus wiring.

Concurrent with the flight test program, work continues on the static test program being conducted at both Lockheed's loads test facility at Palmdale, California, and Vought Aerospace's static testing facility in Grand Prairie, Texas. Testing of the Lockheed static test airframe was initiated during early 1990. Minor structural cracking surfaced on this full-scale durability ground test article during the course of a post-10,000 hour cyclic load inspection. At least one crack was discovered in a bulkhead stiffener on the forward part of the aluminum wing carry-through box. A fix has been developed and will be incorporated on all B-2s, including the static test articles.

CONSTRUCTION AND SYSTEMS:

The B-2A is designed to MIL-STD-1760. It is built primarily of composite materials (approximately 80%) and has a titanioum and aluminum load-bearing internal substructure. Composites consist primarily of high-strength carbon, graphite, or glass fibers woven into a cloth or tape format and a binding, plastic-like polymer which is either epoxy, polyester, or phenolic in origin. The cloth or tape (depending on which is required), is laid into a mold, usually in an over-lapping pattern optimized for post-impregnation strength, and then a polymer is added to form a binding matrix. Once the polymer is injected, the entire piece is checked for mold conformity, voiding, and other anomalies and then placed in a pressurized curing autoclave or hot sterilizer, and baked. Temperatures of 350°or more and pressures of 100 psi or more usually are required to accommodate the curing process. The finished composite part weighs only two-thirds that of a comparable aluminum part and is considerably stronger. Most importantly, it has up to four times the fatigue life of its aluminum counterpart.

As part of the B-2A composites technology package, an automated method for applying and conforming composite tape to contoured tools in the fabrication of structural rib stiffeners (stringers) was developed. This subsequently reduced hand labor by 69%. The technique also was found to improve quality and reduce the amount of scrap material. The machines that performed this operation currently are being marketed to other industries by B-2 subcontractors Cincinnati Milacron (under the name Channel Stringer Laminator) and Ingersoll Milling Machine Co.

LTV Aerospace Aircraft Division developed a number of machines and techniques peculiar to the B-2 that now appear to have set precedent for future aircraft incorporating similar materials technology. Among these are a computer-controlled superplastic forming cell which permits specific shapes of titanium, aluminum, and aluminum/lithium to be manufactured with maximum dimensions of 4 ft. (1.22 m.) by 12 ft. (3.66 m.) and thicknesses of up to .25 in. (.006 m.); robotic abrasive water jet cutters that saw through composite, aluminum, or titanium parts with extraordinary precision (55,000 psi deionized water streams with exit velocities in excess of 1,300 mph [2,092 km/h] serve as the cutting blade); and a computer-controlled, five-axis robotic system (RMA—Robotics for Major Assembly) that drills holes for and installs fasteners while sealing contoured composite or composite/metallic structures as large as 18 ft. (5.49 m.) by 30 ft. (9.15 m.).

Fuselage: Blended center body containing cockpit, two side-by-side bomb bays, and miscellaneous primary and secondary systems. Major structural assemblies all converge into this area which serves to support carry-throughs and associated bulkheads.

Cockpit: Two-seat pressurized and air-conditioned cockpit is equipped with upward-firing (through jettisonable roof panels) McDonnell Douglas ACES II (Advanced Concept Ejection Seat) ejection seats. The junior pilot normally occupies the left seat, and the mission commander/instructor/senior pilot occupies the right. The cockpit, enclosed by four large non-electromagnetically-reflecting transparencies, is arranged and suitably equipped so that either pilot can fly the aircraft. Only select items, such as the landing gear actuation handle, can not be accessed from the right seat.

The cockpit is entered via a retractable ladder assembly mounted to the left and rear of the nose landing gear well. Attached next to the ladder, on the aft rim of the hatch area, is an "instant-on" switch which, when pushed, starts all primary systems in the aircraft including the engines, to permit a near-instantaneous reaction and takeoff time.

The cockpit controls are conventional and consist of a single articulated stick and two rudder pedals for each crew position. Stick movement is left or right, forward or aft. Both pilots, somewhat unusually, have throttle quadrants.

Accommodations for a third crew member remain an option. As these words are written, the B-2A remains essentially a two-man aircraft under the premise that the "all-glass" cockpit and the aircraft's complex and highly automated systems can be controlled by a two-man team. If, in the future, threat and/or systems scenarios become too labor intensive, a third crew member can be added on the right side of the aircraft in an area behind the commander/instructor pilot's position. This third crew member almost certainly would be tasked primarily with operating a more sophisticated defensive electronic countermeasures system.

The cockpit instrument panel is referred to as an "all-glass" system wherein virtually all data is presented in the form of cathode ray tube (CRT) displays. These units, sometimes referred to as multi-function-displays (MFDs) and/or integrated flight information system (IFIS) displays are mounted in groups of four (three on top and one underneath in a "T" layout) in front of each crew member.

Three "master mode" switches serve to permit near-real-time aircraft configuration changes at the push of a button. Configuration options include landing, takeoff, and combat. The latter mode automatically transitions the aircraft's systems into a low-observables or stealth configuration which rapidly turns off all active systems and arms the weapons payload.

Cockpit systems are managed by doubly-redundant flight mission control processors. Cockpit controls and the four approx. 8 in. (20.32 cm.) on a side color displays per pilot are managed by four display processors. Quadruple-redundant digital flight control computers also manage processing for the passive air-data system and attitude-motion sensor set. The latter is a self-contained inertial reference system and allows the flight control system to operate even if all air-data information is lost.

In the event of a complete MFD/IFIS system failure, the left-seat pilot has what Northrop refers to as three small electro-mechanical emergency gauges that provide analog attitude, airspeed, and altitude reference data. Additionally, there is a manual back-up for the automated fuel control system.

The air-vehicle interface processor controls systems such as the radios and radar altimeter. Other processors cover terrain following and terrain avoidance, navigation, and defense and stores management.

Some sources indicate operational B-2As will

have photoreactive layers in the cockpit windscreens to blacken almost instantaneously in response to a nuclear blast. Crews also will wear PZLT goggles for laser protection.

Wings: Virtually all of the aircraft, including the central, or fuselage area, is part of the wing configuration and thus contributes to the total aircraft lift. Construction is primarily graphite or carbon fiber composite construction impregnated with epoxy resin. The wing structural assembly consists of a single spar arrangement with a box type carry-through structure in the central, diamond-shaped part of the fuselage/inboard wing assembly. The outer wing panels are essentially independent assemblies of primarily composite construction. The inboard spar and wing carry-through box assembly is of titanium construction. Other associated assemblies are of aluminum.

Heavy emphasis has been placed on reducing the aircraft radar signature and to that end, extensive use has been made of honeycomb radar-absorbent structure (RAS) with a covering of radar-absorbent material (RAM). Additionally, the entire wing surface area has been covered with radar absorbent paint.

The leading edges, which are covered in what is thought to be a dielectric material and to have an internal structural configuration (believed to resemble that of the Lockheed SR-71) designed specifically to attenuate radar energy, are essentially straight and the leading edge sweep angle is 33°. Leading edge camber varies considerably from the nose of the aircraft to the wing tip as a direct result of varying aerodynamic requirements (see Powerplant section, below).

The trailing edge forms what now is commonly referred to as a "double W" configuration. With the exception of the exhaust recesses, virtually all of the wing trailing edge (and some 15% of the total wing area) consists of movable control surfaces (see Controls section, below).

The wing has no high-lift devices for low-speed flight and is void of leading edge or conventional trailing edge flaps. Forward wing carry-through box section incorporates integrally stiffened composite skins nearly .9 in. (3 cm.) thick in places. The all-composite outer wing sections with integrally stiffened skins up to 72 ft. 2 in. (22 m.) in length are cured in a specially built Boeing 91 ft. 10 in. (28 m.) long autoclave[2]. Production tolerances were plus or minus 1/4 in. (6.3 mm.) across the B-2A's entire wingspan.

The leading edge of the wing, from just outboard of the engine nacelles to the wing tips also is optimized to accommodate transonic airflows, but is configured to provide shock-resistant compression at cruise.

Control Surfaces: The B-2A is equipped with a quadruple-redundant digital fly-by-wire flight control system and an integrated and highly sophisticated stability augmentation system. The latter is thought possibly to incorporate a fly-by-light system as the data relay assembly.

The B-2A's control arrangement is unique, and thus worthy of independent description. The entire trailing edge, with limited exception, is articulated and serves to input pitch, roll, and yaw moments for controlling the aircraft. Split drag rudders are mounted at each wingtip and provide yaw (directional) control; three sets of large elevons provide pitch and roll control; and an empennage-mounted "beaver tail" articulates for gust alleviation at low altitudes. The "beaver tail" is thought also to provide some pitch trim and to optimize span loading dynamics.

The outboard elevons are the primary pitch and roll control surfaces and function throughout the flight envelope. The two sets of inboard elevons are considered secondary pitch and roll control surfaces and function only when the aircraft is operating at low speed. The aircraft's angle-of-attack is limited through the quadruple-redundant computer interface with these surfaces.

Control surface positions, accomplished through a system of from two to three hydraulic rams per surface, are considered somewhat unorthodox during takeoff and in flight, and it is not until the aircraft is operating in high-speed cruise mode that all of the surfaces are faired flush in a conventional fashion. During the beginning stages of the takeoff roll, for instance, all three elevon sets droop until sufficient airspeed is attained. This has been done to prevent surface damage in the event of hydraulic system failure during takeoff and to provide a built-in nose-down pitching moment. In flight and at low airspeeds, the drag rudders are biased open with maximum extension angles estimated to be approximately 45°.

Tail Surfaces: "Beaver tail" (see Control, above) has flexible material covering hinge gap. "Beaver tail" construction is presumed to be primarily composite. Articulation is via hydraulic rams.

Landing Gear: The Boeing Military Airplanes Division designed and manufactured landing gear is of the conventional tricycle type. The nose gear, which retracts aft via a single Dowty Decoto, Inc. hydraulic ram, is a twin-wheel, fully-steerable unit. Two taxi/landing lights are mounted one above the other on the left side of the nose gear upper main strut assembly.

The nose gear well is covered by two doors. One door is permanently affixed to the main gear strut assembly, and the second, main door is independently hinged on the right side of the well and is hydraulically opened and closed.

The main landing gear, which retracts forward and up via a single Dowty Decoto, Inc. hydraulic ram, each have articulated four-wheel main bogies and large anti-torque assemblies. Main landing gear brakes are of the carbon disc type.

Each main gear well is covered by a large, single door assembly independently hinged on the outboard side of each well. Each door is equipped with a single hydraulic ram for opening and closing in sequence with gear extension and retraction.

All landing gear well doors feature serrated forward edges that minimize radar returns from the gaps between the doors and the well edges. When parked statically, these serrated edges are provided a special plastic protective cover.

Landing gear extension or retraction cycle time is approximately 15 seconds. Landing gear never exceed speed is 258 mph (415 km/h). Landing gear track is 40 ft. 0 in. (12.2 m.). All tires are manufactured by Goodyear Tire and Rubber Co.


Northrop

B-2A is stated to be an extremely stable inflight refueling platform.

Powerplant: B-2A is powered by four General Electric F118-GE-100 non-afterburning turbofan engines rated at 19,000 lb. (84.5 kN) thrust each and mounted in pairs in individual wing bays on either side of the two weapons bays. These bays are accessed via large hinged RAM-covered panels on the underside of the aircraft. Each engine drives an airframe-mounted accessory drive which has reduction gearing to power generators and hydraulic pumps.

The F118-GE-100 utilizes the core of the F101-GE-102 developed for the Rockwell International B-1B. Work on the F118 in its present configuration was initiated by General Electric during 1983. It has the same fan diameter and stator case configuration as the General Electric F110 turbofan engine used on the General Dynamics F-16C/D and Grumman F-14D. Its airflow capacity and pressure ratio, however, are considerably higher and thus its thrust is considerably greater. The production line for the F118 is the same as that used for the F110.

The B-2A's F118 engines are equipped with a number of special, low-observables-related systems including devices for mixing ambient air with hot exhaust gases in such a way as to lower the temperature of the exhaust plume, and a special chlorofluorosulfuric acid system that injects this mixture into the exhaust in order to attenuate the development of vapor trails at altitude.

Most importantly, the B-2A's intake configuration is optimized to reduce engine compressor face radar returns to an absolute minimum. Accordingly, the ducts are "S" shaped with the engine sitting nearly one engine diameter lower than the actual intake.

The leading edge of the wing, from the nose of the aircraft to just outboard of the engine nacelles is designed to entrain airflow into the intakes within the aircraft angle-of-attack limits. Airflow over this lip, at the aircraft's transonic cruise speed, is flowing at near-sonic velocities, so design of the intakes, much like that of an aircraft capable of supersonic speeds, is optimized to slow engine compressor face air to subsonic velocities. The boundary-layer-air slots ahead of and inside the intakes bleed turbulent flow away from the intake walls and also serve to provide ram air for environmental control and internal compartment venting.

Intake design accommodates the increased flow demand that takes place above the wing and the fact that air enters the intake from all quarters, and not just directly ahead. The intake lip configuration is partially the result of this requirement but it also serves to accommodate the supersonic flow field generated when the aircraft is in high-speed

[2] A back-up aluminum outer wing panel was designed, but apparently never built due to the success of the composite panel. Additionally, Boeing tested the basic construction technique of the B-2A's composite outer wing panel by first building a composite horizontal stabilizer for a company-owned Boeing 727. Successful trials then led to the manufacture of the B-2 panel.

Recently released by Lockheed are the first photos depicting the enigmatic "Have Blue" low-observables testbed for what later became the F-117 program.

Three-view drawing depicting the general arrangement of the "Have Blue" prototype. Three of these aircraft are thought to have been built by Lockheed.

cruise. Auxiliary intakes also are provided, these serving to meet mass flow needs when the engines are forced to operate statically or in a low airspeed environment. Auxiliary inlet doors on top of the engine nacelles take about 3 seconds to close or open. They operate as a function of Mach number.

A triangular upper surface door serves as the exhaust port for the Garrett-manufactured auxiliary power unit. It is located outboard of the left engine nacelle.

Special heat-resistant carbon tile construction materials are used aft of the engine exhaust to both absorb heat and protect supporting trailing edge structure.

An inflight refueling receptacle of the SAC-type that rotates into the exposed position is mounted directly on the fuselage centerline on top of the fuselage approximately 13 ft. (3.96 m.) aft of the cockpit.

Fuel type is JP-8 and fuel quantity is approximately 165,000 lbs. (74,844 kg.).

Weapons/Sensors: All B-2As with the exception of twelve early aircraft will have dual nuclear/conventional weapon capability as defined by MIL-STD-1760. The aircraft will be capable of accommodating a single Boeing Advanced Applications Rotary Launcher in each of two weapons bays. Weapons load includes: 16 Boeing AGM-69A SRAMS or AGM-131A SRAM II; 20 B-61 or 16 B-83 free-fall thermonuclear weapons; or up to 80 conventional free-fall weapons (including the MK36, MK62, MK82, MK117, and others). Additionally, a new stealthy cruise missile is under development by General Dynamics. Expected to have a range in excess of 125 miles, it remains a politically controversial weapon primarily because of its $2 million unit price tag.

Main B-2A "covert strike" radar is the Hughes AN/APQ-181 LPI (Low Probability of Intercept) synthetic aperture (SAR) unit developed by the Strategic Systems Division of the Radar Systems Group of Hughes Aircraft Company. Hughes won the development contract for the radar in the early 1980s. With dual phased-array antennas (one antenna is mounted ventrally on each side of the nose landing gear well and faces forward and down behind faired dielectric panels), the AN/APQ-181 features a substantial amount of commonality with radars now in production at Hughes. Like these other systems, it is controlled and operated by a sophisticated digital computer, includes a fully programmable high-speed digital radar signal processors, and is delivered with thorough built-in test (BIT) software for fault detection and isolation. It operates in Ku-band and has 21 operational modes, including high-resolution ground mapping, navigation, penetration of defended areas, and target search and detection.

The radar development program is nearing its end. Several sets of engineering development and pre-production equipment have been delivered and are in various stages of development and qualification testing. Testing to date continues to be successful and indicates the radar will satisfy its performance and reliability specification. Hughes acknowledges being under contract to produce a limited number of production radar units in anticipation of production aircraft deliveries.

Miscellany: The B-2A is equipped with an advanced air data sensor system which is the first of its kind to respond to the requirements of low-observables technology. The external sensor heads for this system are visible as four small circular plates above the cockpit windscreen, twelve small circular plates just aft of the nose section of the upper wing leading edge, and four small circular plates mounted under the wing leading edge.

Other systems purported to be utilized by the B-2A include a Rockwell Collins TCN-250 Tacan; a VIR-130A ILS; and a ICS-150X intercom.

During the early 1980s, Northrop formed an ILS (Integrated Logistics Support) team of former air Force maintenance personnel who had a total of 1,600 years experience maintaining dozens of aircraft types. This team studied and analyzed more than three million flight hours work of maintenance data from 14 military aircraft to determine which subsystems were responsible for most breakdowns and how failures could be reduced. Northrop then made the ILS group part of the company's B-2 design team. The ILS group worked with design engineers early in the design process to build reliability and maintainability into the aircraft systems and subsystems.

B-2 flight validation maintenance highlights from the first 67 flight hours include:

(1) Initial validation of the B-2's unique "zoned" design in which components with the lowest reliability are placed in front of components with the highest reliability. This ensures mechanics don't have to remove something that seldom malfunctions to get to something that malfunctions more frequently.

(2) No rack-mounted component connector failures. Conventional components connectors often fail when subjected to the vibration, stresses and severe temperature changes that occur during flight as well as misalignment during installation. Northrop designed a new component connector for the B-2 that is much less likely to fail during flight and has not failed in flight test.

(3) An average of only a dozen pilot written notices of anomalies per flight.

(4) No fuel leaks.

(5) No hydraulic leaks. Joints in the hydraulic system are cryogenically sealed. Fittings are immersed in liquid nitrogen before being connected to tubing. When the joints warm to normal temperatures, they are permanently bonded.

(6) All B-2 accumulators are serviced from two points, and it takes less than fifteen minutes to service them all.

(7) The conventional access for aircraft servicing is through panels on the aircraft's outer skin. These panels are minimized on the B-2 due to their negative impact on low observable performance. Centralized servicing has been applied to many of the B-2's systems such as the fuel, hydraulic fluid, and engine oil reservoir systems.

(8) Initial validation of the B-2's On-Board Test Systems (OBTS)—a sophisticated system that automatically tests, reports, and records data from thousands of B-2 components and systems—has been successfully completed. A unique part of the OBTS is its on-board maintenance printer (OBMP), located in the cockpit. The OBMP prints out a list of faulty line replaceable units (LRUs) or items that need servicing and gives the status of consumables like hydraulic fluids and engine oil.

The first B-2A, 82-1066, was equipped with a temporary wire-extendible trailing cone to measure static pressure away from airframe aerodynamic disturbances.

Weight savings will be realized starting with AV-12 (the 6th "production" aircraft) when a new electrical wiring system is utilized.

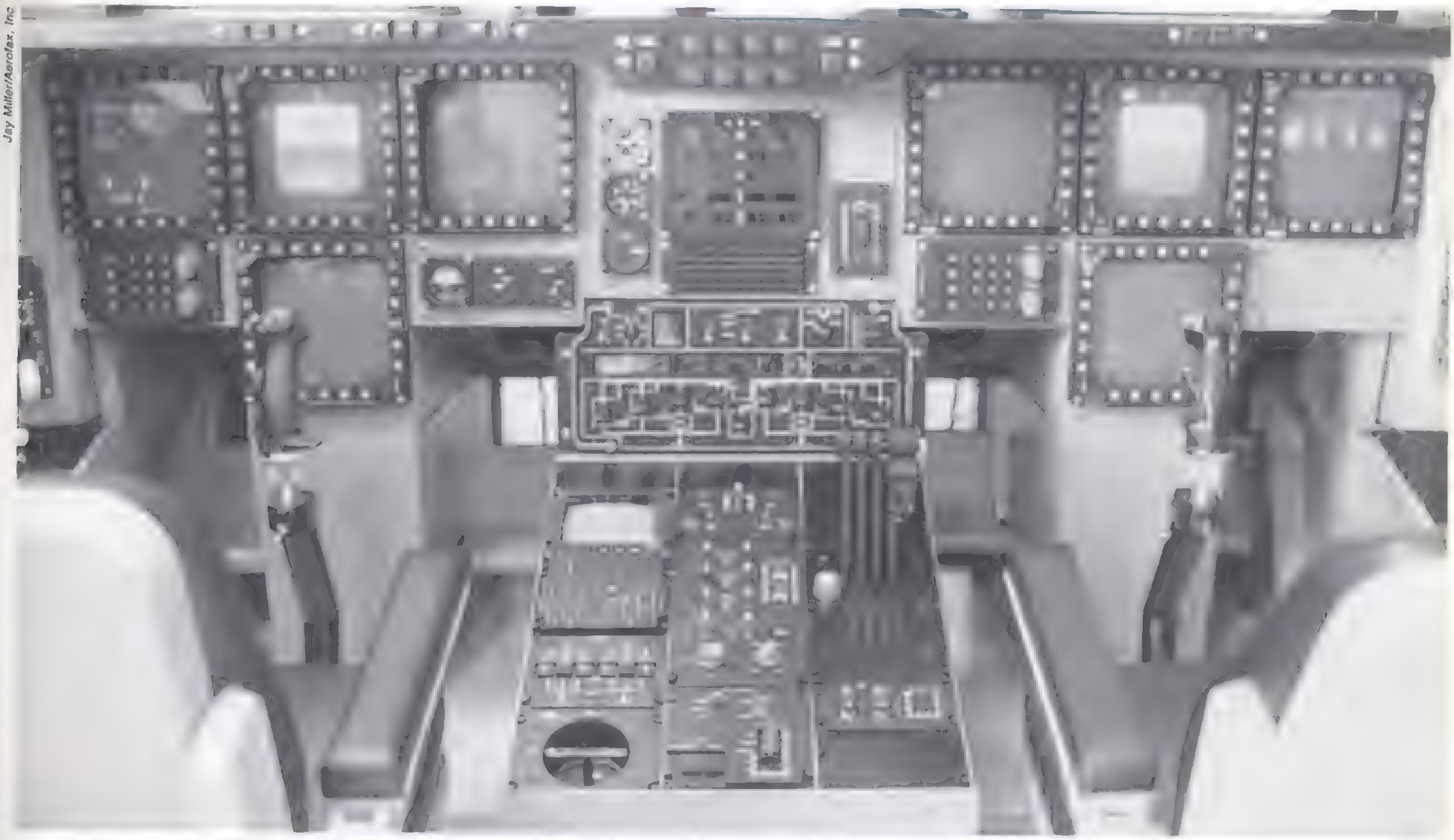
Avionics center on a 1553B multiplex digital databus. It uses an architecture frozen early to allow the avionics to be hardened against the electromagnetic pulse effects of nuclear combat.

The aircraft has a 4,000 psi hydraulic system.

The prototype B-2A was equipped temporarily with "radar signature enhancers" similar to those found on the F-117.

IN DETAIL:

Jay Miller/Aerofax, Inc



Instrument panel of B-2A cockpit simulator. Main instrument panel is a facsimile of that actually found on operationally-configured B-2As. Panel is dominated by CRT-type displays, of which there are four primary viewing screens for each of the two crew members. The screens, upon pilot command, present data of many different kinds.

Jay Miller/Aerofax, Inc

Left console area of B-2A cockpit simulator. Visible are throttle quadrant, landing gear retraction/extension handle, and controls for Hughes AN/APQ-181 radar.

Jay Miller/Aerofax, Inc

Right console area of B-2A cockpit simulator. Visible are controls for Hughes AN/APQ-181 radar, seat adjustment switch, and miscellaneous communications controls.

Jay Miller/Aerofax, Inc

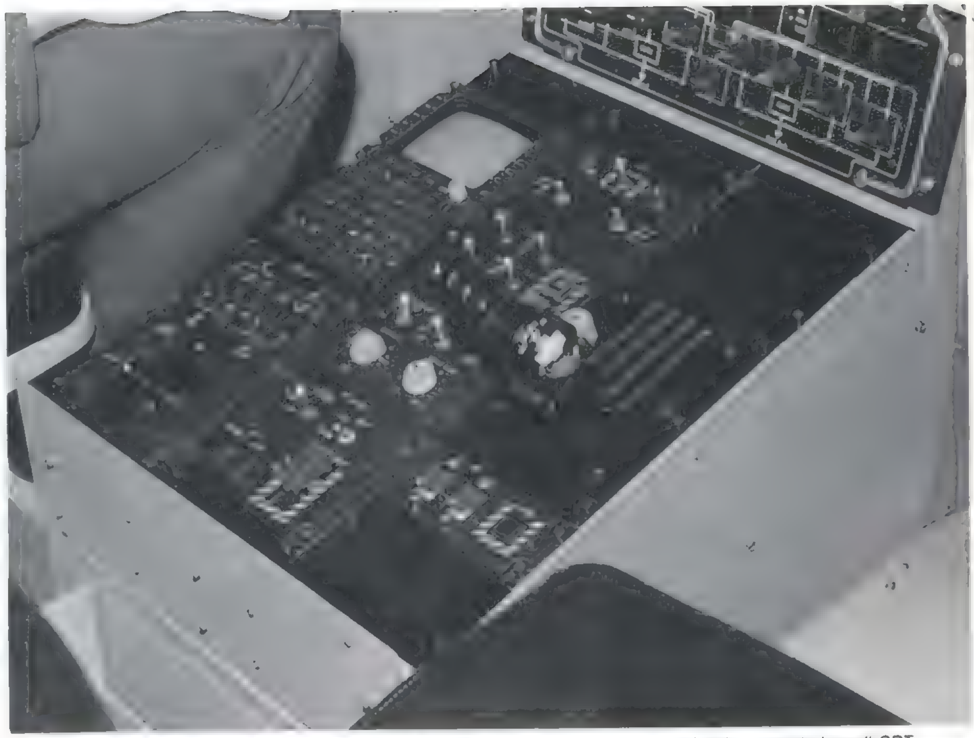
Left console of B-2A cockpit simulator. Radar grip with associated operations mode switches is readily discernible just ahead of seat arm rest.

Jay Miller/Aerofax, Inc

Right console of B-2A cockpit simulator. Communications panels, the radar control grip, and CRT-equipped panel for data input are all readily discernible.

Jay Miller/Aerofax, Inc

Overhead panel mounts engine start, lighting, and -3 opening and closing entry hatch switches.



Jay Miller/Aerofax, Inc

Center console mounts right crew member's throttle quadrant, data input panel with associated small CRT, cockpit environmental controls, ejection seat mode control handle, and control system override switches.

Aerofax, Inc collection

Testing of B-2A main instrument panel and associated systems took place aboard C-135A, 60-0377. Navigation and associated weapons system operations were the main thrust of these tests. C-135 was extensively modified with several panel arrangements such as this one scattered along fuselage interior. Note AN/APQ-181 radar control grip in the center.

Aerofax Inc collection

Boeing C-135A, 60-0377, as modified for B-2A systems tests. Noteworthy are ventral fairings to accommodate B-2A radar and radar altimeter-related systems.

Aerofax, Inc. collection

Model of Boeing C-135A, 60-0377. Visible along fuselage dorsal spine are various antenna, antenna fairings, and star-tracking system fairings.

Aerofax Inc collection

Because Boeing C-135A, 60-0377 was equipped with a large number of B-2A systems that required a considerable amount of electrical power, its engines were equipped with special power takeoff units that drove over-sized electrical generators. Intakes for cooling these units are visible as abbreviated fairings on the left side of each engine nacelle.

Aerofax Inc. collection

B-2A astroinertial navigation system is extremely accurate in order to meet weapons system needs. Special sensor window is visible lower right.

Aerofax, Inc. collection

Computer-generated drawing of B-2A forward windscreen center frame assembly and upper cockpit crown. Construction material are unidentified.

Northrop

Northrop

B-2A cockpit windscreen is laminated acrylic material impregnated with special photoreactive layers to instantly block out the intense and potentially blinding light generated by a nuclear explosion. Additionally, the windscreen almost certainly will be given some form of gold film laminate to reduce the cockpit radar return.

Jay Miller/Aerofax, Inc

Jay Miller/Aerofax, Inc

Windscreen and two side panels make up total transparency surface area. Ahead of forward panels are slots for windscreen cleaning system. The latter consists of a high-pressure air system derived from engine compressor section hot bleed-air. The slots are aerodynamically faired and consequently conform to low-observables requirements.

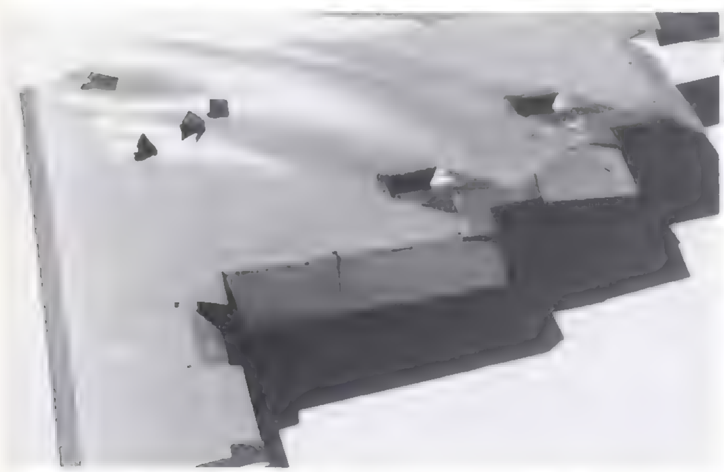
Jay Miller/Aerofax, Inc

Cockpit is accessed via an extendible, two-part, fold-down ladder, an associated entryway, and a cover hatch/door.

Northrop

B-2A is equipped with three emergency egress panels on the top of the fuselage. These panels are explosively jettisoned in the event of ejection seat use.

Northrop



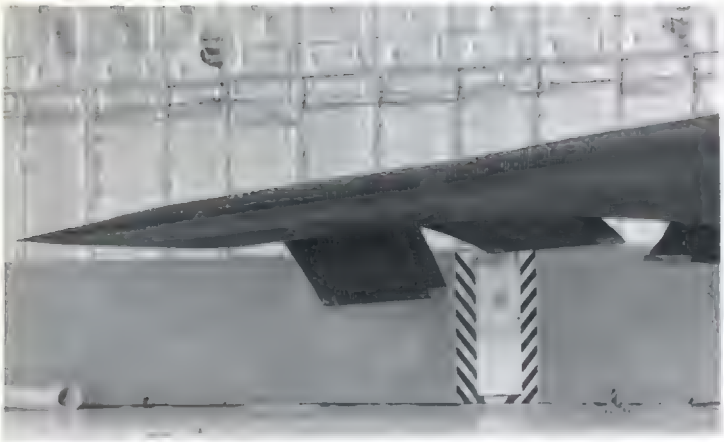
B-2A wing trailing edge control surfaces make up 15% of the total wing area and approximately 90% of the total wing trailing edge area.

Northrop

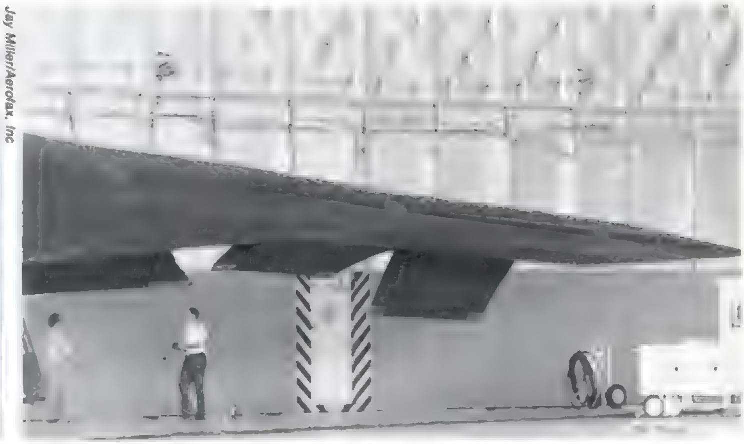
B-2A wing leading edge is extremely complex and varies considerably in camber and design along entire span of aircraft, from nose to wing tip.

Northrop

Split drag rudders accommodate yaw needs; inboard elevons accommodate pitch and trim along with the "beaver tail"—which also accommodates gust response.



Jay Miller/Aerofax, Inc

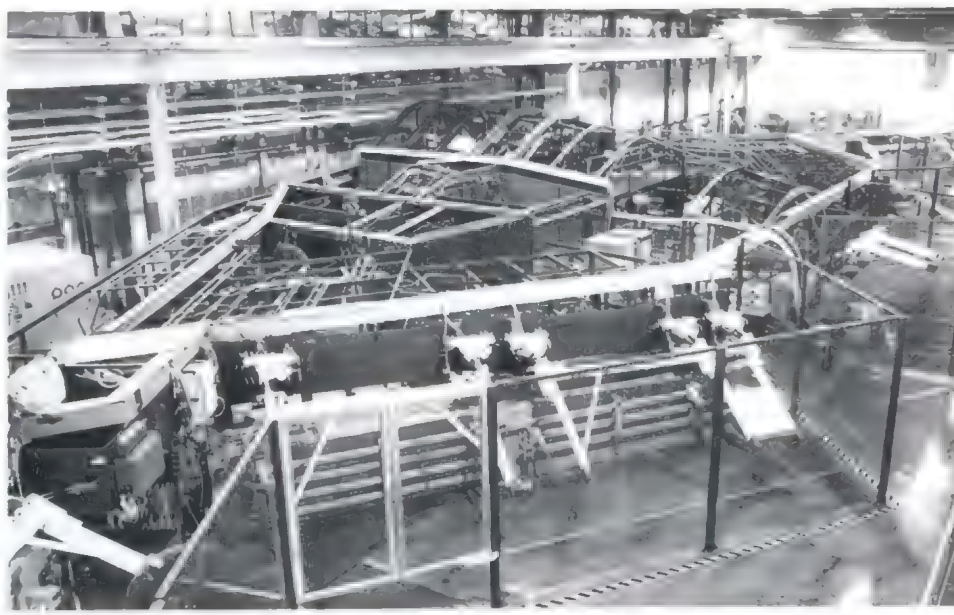


Jay Miller/Aerofax, Inc

B-2A's trailing edge control surfaces, when the aircraft is sitting statically without power, have varying degrees of droop apparently as a result of the hydraulic system arrangement. Leading edge variations also are visible in this view. Faired cut-outs in leading edge are thought to be passive countermeasures system sensor antenna locations.

Northrop

B-2A hydraulic system actuators during the course of some 9,000 hours of static test work.



Northrop

A full-scale ground test unit was built to permit detailed study of the B-2A's complex, computer-driven hydraulic actuator system for the aircraft's numerous trailing edge control surfaces.

Northrop

Because of the low-observables philosophy behind the B-2A's design, a totally new, faired static sensor system had to be developed. A total of twenty sensor ports are mounted in the nose area, with four being positioned above the cockpit, twelve being positioned ahead of the windscreen, and a final four being positioned under the nose leading edge.

Jay Miller/Aerofax, Inc

The nose landing gear retracts aft into a large well. It is hydraulically steerable and is equipped with a pair of over-and-under-mounted taxi lights.

Jay Miller/Aerofax, Inc

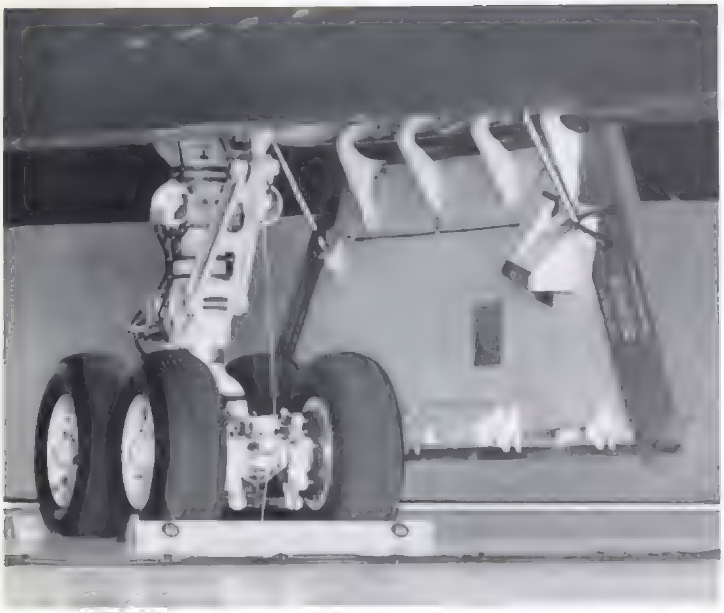
The nose gear well is covered with a fixed gear door and a secondary door that is hinged on the right side of the nose gear well. All are hydraulically actuated.

Jay Miller/Aerofax, Inc

Attachment points for avionics air conditioning ducts in static condition are positioned in the composite construction nose gear well.

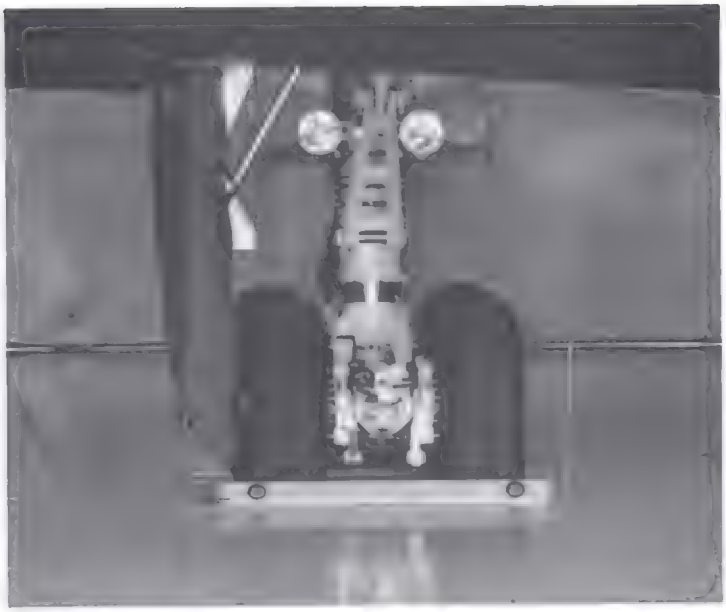
Jay Miller/Aerofax, Inc

The main landing gear wells each are covered by a single large door attached to the outboard edge of each main gear well by four large hinges.



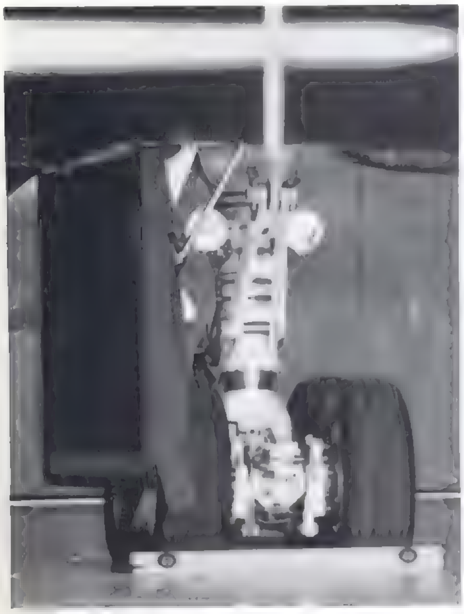
Jay Miller/Aerofax, Inc.

The main landing gear retract forward in conventional fashion via a single large hydraulic ram. The main gear wells are built entirely of composite materials.



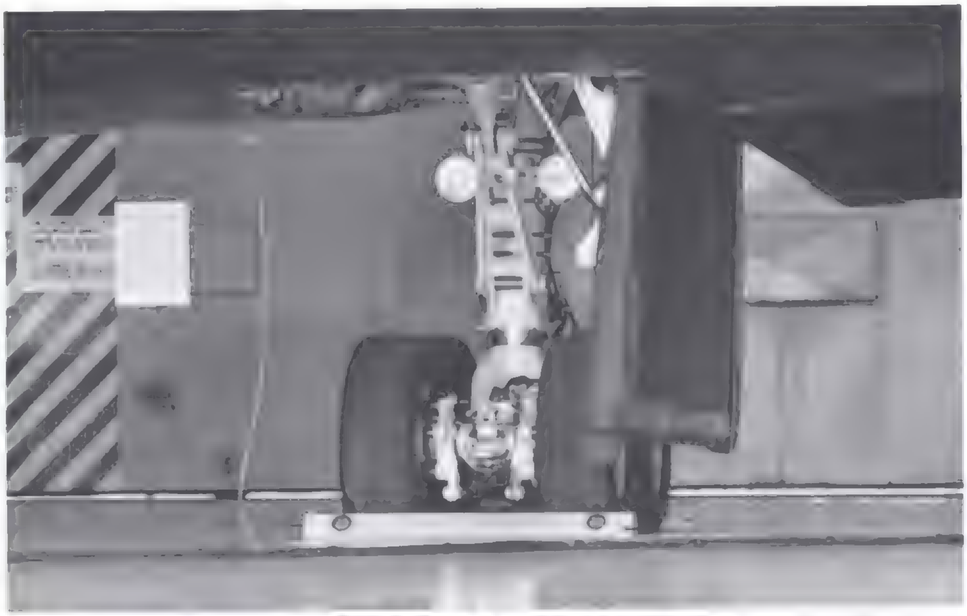
Jay Miller/Aerofax, Inc.

In static position serrated edges of main landing gear well doors are covered with protective red-colored boxes for protection.



Jay Miller/Aerofax, Inc.

Each main gear wheel is equipped with a large carbon-type disc brake assembly.



Each main gear is equipped with a pair of fixed taxi lights. The main gear wells are located immediately adjacent to the outboard engine bay in each wing. Noteworthy are door leading edge covers.

Landing gear displacement has made the B-2A an extremely stable aircraft during taxiing, takeoff, and landing. The landing gear assemblies are rumored to have been derived from that of the Boeing 767 airliner, but an actual comparison of the two reveals limited similarities. Size of nose gear tires is noteworthy.

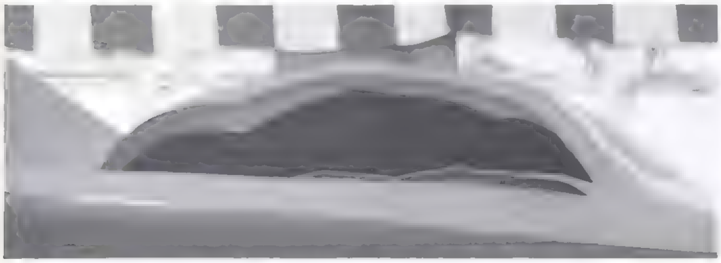
Jay Miller/Aerofax, Inc.

Pattern in right intake is not replicated in left, indicating the latter has been coated with a radar absorbent paint for test purposes.

Northrop

Intake design is highly complex with special consideration being given radar return. A boundary layer bleed slot forms lower lip assembly.

Jay Miller/Aerofax, Inc



Composite intake lip design is optimized to reduce radar return while offering optimum transonic flow patterns in cruising flight.

Northrop

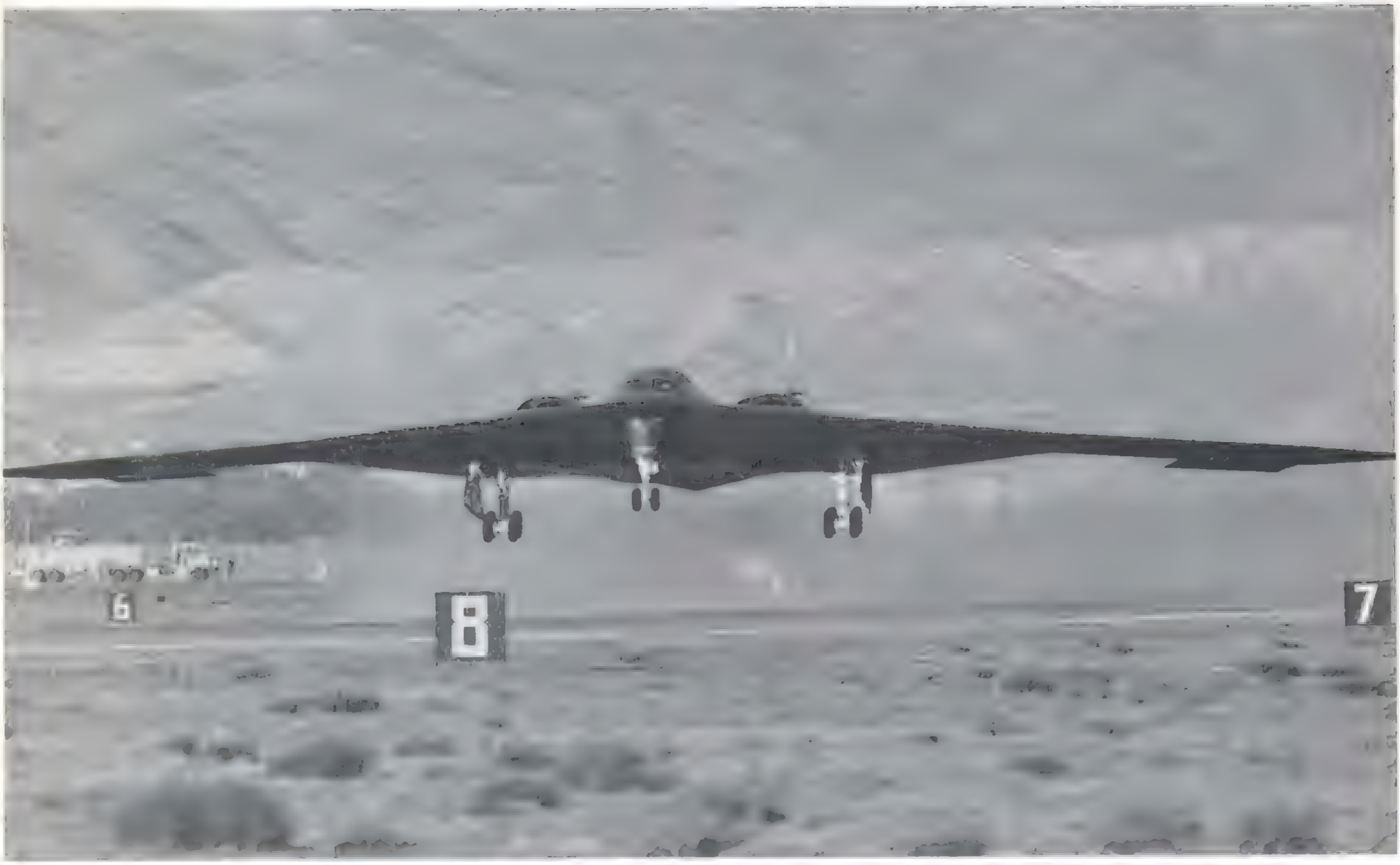
Each engine nacelle is equipped with a pair of hydraulically actuated auxiliary intake doors to provide optimum mass flow to engines at idle power.

Northrop

Close-up of auxiliary intake doors indicate few concessions to high-speed airflow. Tube-like device protruding at left is unidentified.

Northrop

Auxiliary intakes remain open throughout the ground operation process and do not close until well after the aircraft has become airborne and the gear have retracted. Operation of the doors appears to be computer programmed and is directly related to airspeed. An auxiliary power unit intake is located on the left side of the aircraft.



Northrop

B-2A, 82-1066, airborne at the beginning of its first flight on July 17, 1989. With weight off the landing gear, the struts are fully extended. Auxiliary intake doors also are fully open, as is auxiliary power unit intake door. Note, too, the position of the split drag rudders located near each wingtip.

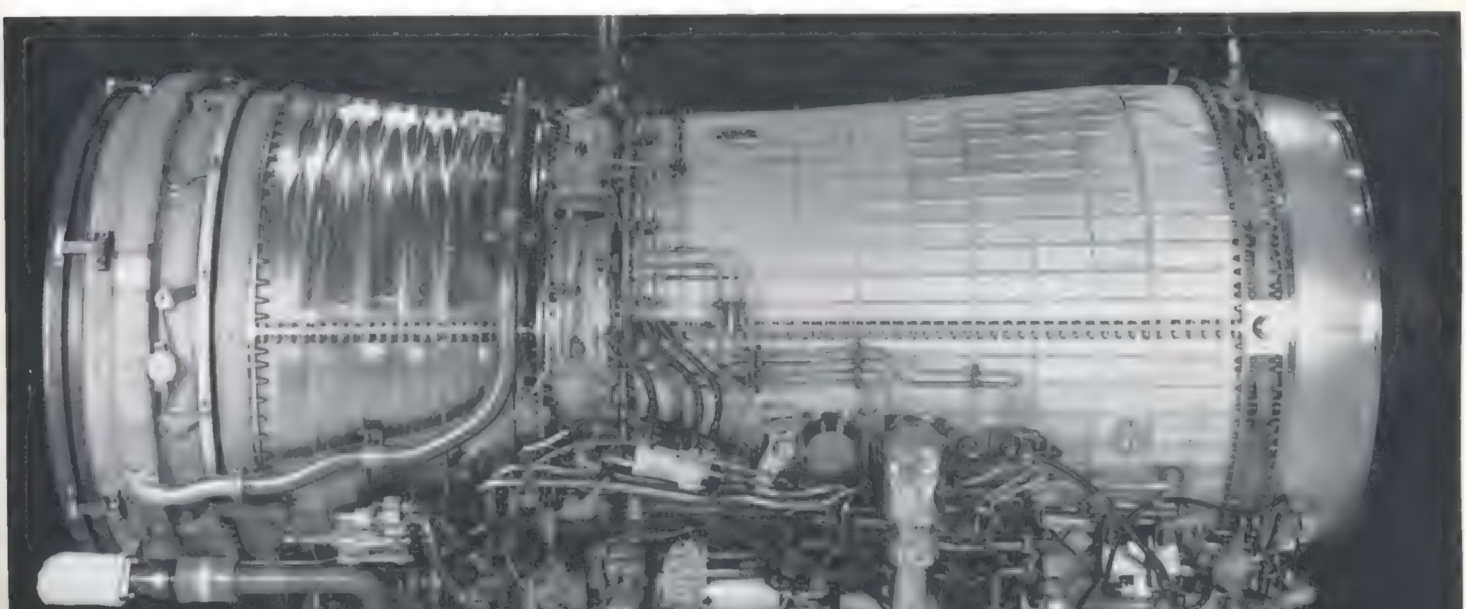
Northrop

B-2A, 82-1066, viewed from the rear as it reaches rotation speed during takeoff. Auxiliary intake doors are open, "beaver tail" surface is slightly trailing-edge-down, and there is virtually no discernible exhaust smoke (though the heat plume appears to be quite substantial). Exhaust ducting appears to be roughly rectangular.

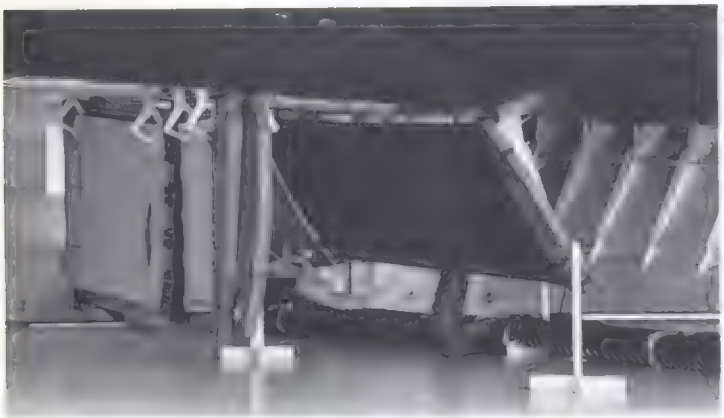
Northrop

Engine exhaust details remain difficult to discern, though this view provides some insight. There appear to be several systems for reducing heat emissions, not the least of which is the recessed position of the nozzles. Noteworthy are "beaver tail", open auxiliary intakes, and open auxiliary power unit intake (outboard of left engine fairing).

General Electric



The General Electric F118-GE-100 non-afterburning turbofan engine incorporates the same fan diameter and stator case as the F110 engine. However, the F118 has a higher airflow capacity and higher pressure ratio than the F110, thus providing considerably higher thrust. The F118 technically is a derivative of both the F110 and F101 engines.



Jay Miller/Aerofax, Inc.

The B-2A's engines are accessed via fold-down doors mounted on the underside of the fuselage between the bomb bays and the main landing gear wells.

Northrop

Seen in its rotated open position, the inflight refueling receptacle, when closed, is a perfectly flush component of the upper fuselage.

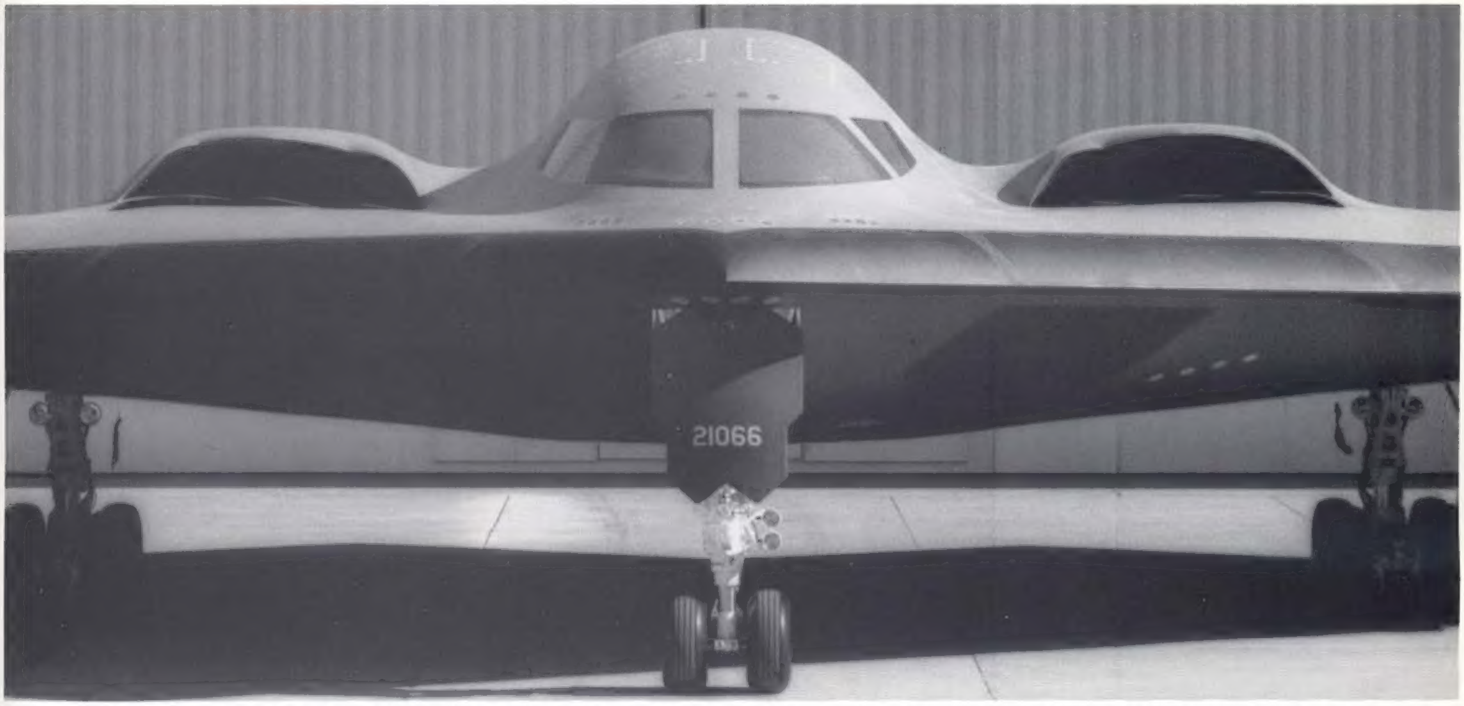
Northrop

The B-2A is inflight refuelable via a dorsally-mounted rotating receptacle mounted on the fuselage centerline, just after of the cockpit area.

Air Force

The B-2A has been found to be compatible with the two primary Air Force tankers, the Boeing KC-135A and the McDonnell Douglas KC-10A (shown). Because of the receptacle's dorsal and aft location, the B-2A pilot is forced to rely on data provided by the tanker for proper positioning during the refueling process.

Northrop



The B-2A apparently is equipped with two Hughes AN/APQ-181 synthetic aperture low probability of intercept radar units which are positioned to the left and right of the nose landing gear behind advanced dielectric paneling. One of these panels is visible to the right of the nose gear in this view.

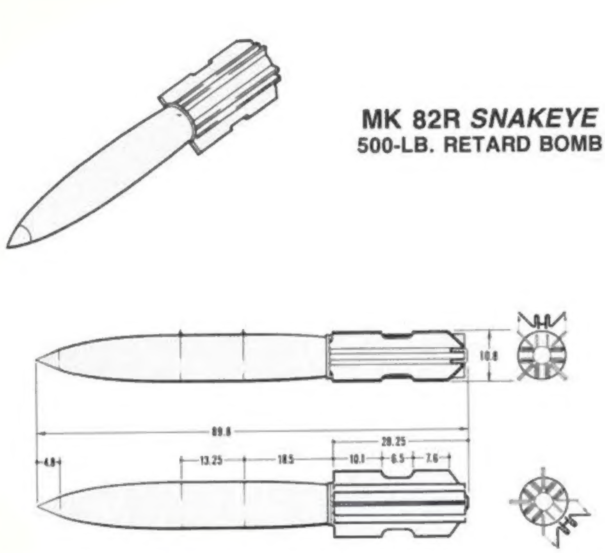
Jay Miller/Aerofax, Inc.

Jay Miller/Aerofax, Inc.

Dielectric panels for the Hughes AN/APQ-181 synthetic aperture low probability of intercept radar are readily visible in these two views. Positioned just to the left and right of the nose landing gear well, they appear to have a downward and forward orientation, probably in consideration of their advanced terrain following and mapping capabilities.

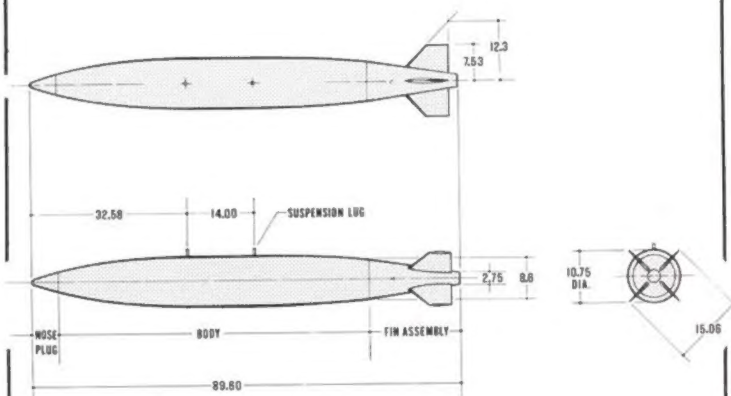
Jay Miller/Aerofax, Inc.

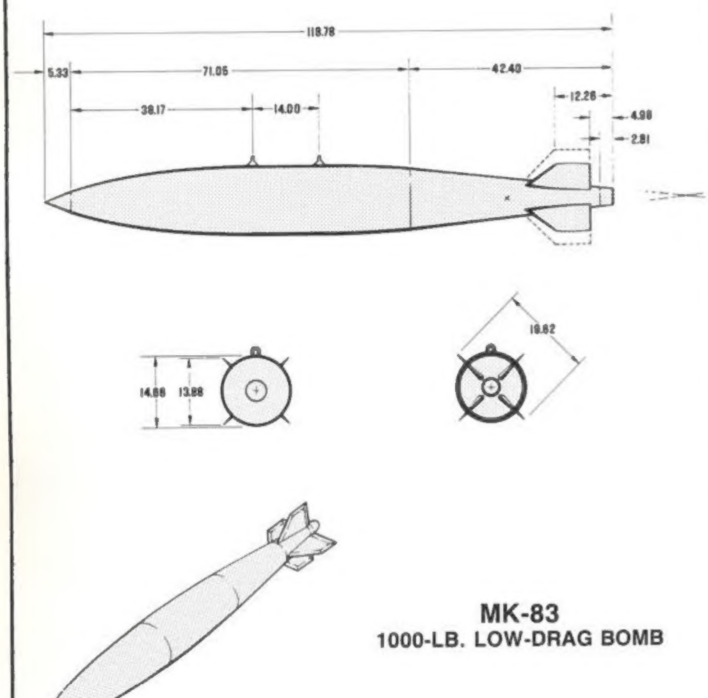
The B-2A is equipped with two bomb bays, each provided two hydraulically actuated door assemblies. Each door is equipped with no less than six hinge fittings. Each bomb bay can be equipped with a Boeing Advanced Applications Rotary Launcher. Weapons loads include short range attack missiles, thermonuclear bombs, or conventional free-fall weapons.



MK 82R *SNAKEYE*
500-LB. RETARD BOMB

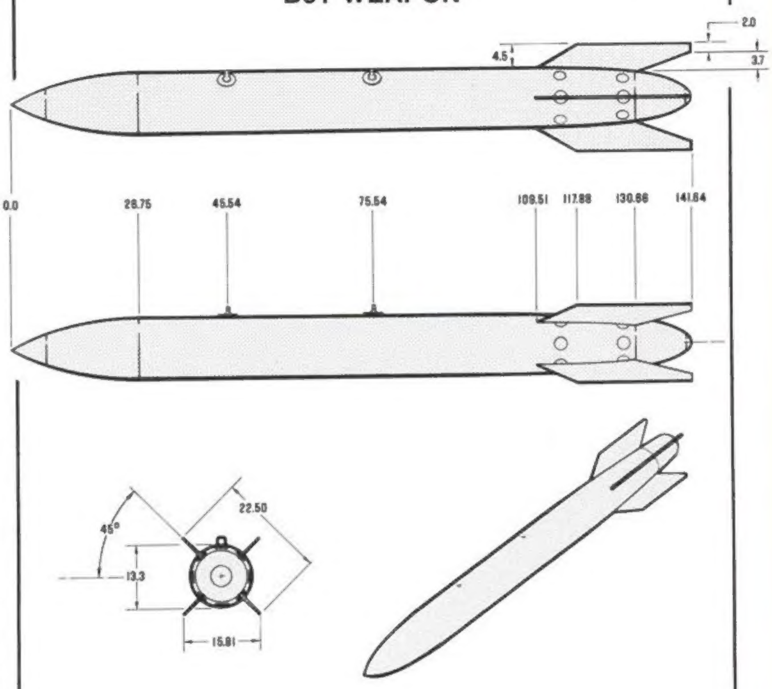
MK-82 LDGP
500-LB. LOW-DRAG BOMB





MK-83
1000-LB. LOW-DRAG BOMB

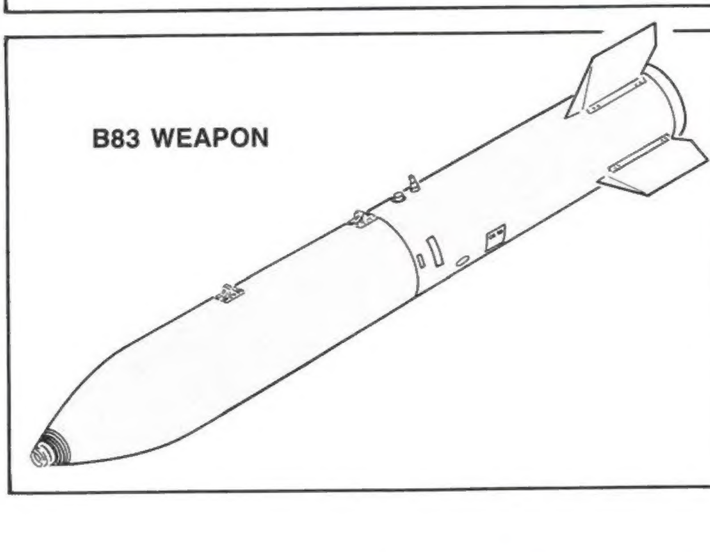
B61 WEAPON




Northrop

Artist's rendering depicts B-2A launching a stylized advanced short-range attack missile. The B-2 is capable of carrying up to sixteen SRAM or SRAM IIs.

B83 WEAPON



The following information is supplied by Hughes Aircraft Radar Systems Group:

AN/APQ-181 RADAR MODES AND SOFTWARE:

Specified radar performance requirements are organized by operating modes. Radar modes enable and support operation of the bomber in its several mission sequences identified above. For example, the B-2 is capable of autonomous navigation (without benefit of the Global Positioning System [GPS] or any other external navigation aid) from departure base to the target and on to the recovery base. The radar has operating modes such as precision position and velocity update measurement to enable highly accurate inertial navigation. A related mode provides altitude measurement.

The radar performs vital functions during penetration of defended hostile airspace. The several radar modes available during this phase of a B-2 mission provide information about natural (terrain) and man-made (towers) hazards to flight to the aircrew and mission management avionics. Radar-made images and measurements enable the B-2 to navigate safely over and around hazards while using these hazards to its advantage to mask defensive systems sensors and to minimize the possible time of observation by these sensors.

During the target search, acquisition, identification and attack phase of a B-2 mission the radar operates in a variable resolution synthetic aperture radar (SAR) mode to precisely locate and identify assigned targets. The radar has other modes and submodes which enable and enhance B-2 operations in this mission phase. Typically in the SAR mode, the radar quickly makes a topographic map-like, high quality image at resolutions which are independent of radar range, and provides them to the aircrew for evaluation. Not only are these radar modes useful for locating targets, they also confirm the delivery accuracy of weapons previously delivered by other vehicles.

From a radar point of view, the hostile airspace egress mission phase is similar to the penetration phase and employs similar radar modes. It should be noted that there is no particular set of radar modes for each B-2 mission sequence, any mode may be selected and operated at any time the aircrew operator decides radar measured information is needed. It is also noted that some radar modes, such as inertial navigation update in non-hostile airspace, are under B-2 mission computer control and are selected when the mission computer senses that it needs radar measured information.

So far in this discussion there has been nothing described which is unique to the B-2 radar. In fact, the modes identified above are very similar to those in other contemporary strategic bombers. The important unique feature of B-2 radar modes is their design for low probability of intercept (LPI) operation. Like low observables ("stealth") technology, low probability of intercept technology is a collection of individually effective design and operating techniques that, when well integrated, greatly diminish the effectiveness and range of radar frequency (RF) intercept sensor systems. These intercept receiver (also known as emitter location) sensor systems are expected to attempt to detect and track the B-2 by detecting and tracking the energy transmitted by its radar. LPI radar techniques include unique performance features built-in the B-2 radar hardware and operated under radar mode control. Understandably, LPI radar techniques are highly classified and are likely to remain so for the foreseeable future. Suffice it to assert they are very effective as implemented in the B-2 radar.

The B-2 radar has 21 distinct operating modes, including two versions of built-in test for radar fault detection and isolation to a line replaceable unit (LRU), or in the case of the antenna, a line replaceable module (LRM). "Line replaceable" used here means a small (less than 200 lbs. in the case of a unit) electronic box or circuit assembly or board ("module") that is capable of removal from and replacement in a B-2 by technicians without special equipment while the aircraft is on the flight "line". Each mode has its own software program, which is an assembly of functional code modules that provides detailed radar operating instructions. In fact, each mode has two sets of software: one for the radar data processor (RDP), which is a militarized general purpose computer, and one for the radar signal processor (RSP), which is a high speed, special purpose computer. The RDP is a MIL-STD-1760A Airborne Computer Instruction Set Architecture machine and is programmed in the MIL-STD-1589B JOVIAL (J73) higher order computer language. The structure of B-2 radar mode RDP software is similar to that for the F-14, F-15 and F/A-18 fighter radars developed by Hughes Aircraft Company. The RSP is programmed in highly efficient machine language to maximize signal processing throughput.

AN/APQ-181 RADAR HARDWARE:

In addition to the radar signal and data processors identified above, there are three additional units in a "radar string": Antenna, transmitter, and receiver/exciter. There are two of each unit, arranged in a string in a B-2 shipset. The strings are functionally connected so that either antenna may be connected to either of the four units in a string. This approach to redundancy maximizes the radar mission probability of success.

The radar equipment is installed in the vehicle in three zones. Each antenna is mounted in a radar antenna cavity behind a large radome, approximately eight feet outboard of the aircraft centerline and below the leading edge of the wing/body. Each antenna has a large unobstructed field of view forward and to the side of the aircraft fuselage reference line (FRL). Six (two each of the transmitter, receiver/exciter, and RSP units) of the other eight units are located symmetrically in openings in each side wall of the nose wheel well; the two RDPs are located one above the other in an opening in the aft wall of the nose wheel well.

The B-2 radar operates in Ku band (12.5 to 18 GHz).

The radar antenna is electronically steered in two dimensions and features a monopulse feed design to enable fractional beamwidth angular resolution. The antenna includes a beam steering computer, which determines and commands the phase settings of the beam steering phase shifters in response to a pointing direction command from the RDP. The antenna is fitted with a motion sensor subsystem (MSS) subunit, which is a modified strap-down inertial platform used to measure antenna motion to enable critical motion compensation during SAR mode operation; Smiths Industries designed and manufactures the MSS. The antenna is equipped with its own power supplies and is liquid cooled.

The antenna is the one APQ-181 radar unit that has no evolutionary relationship to any existing or emerging Hughes Radar Systems Group airborne radar product line. The antenna is designed to have carefully controlled and very low scattering performance (low radar cross section) with respect to both-in and out-of-band radar frequency (RF) illumination. One consequence of this design is that manufacturing tolerances are extremely tight in all the internal RF signal paths of the antenna. This, in turn, required development of advanced machining techniques and inspection to fabricate the antenna.

The radar transmitter is a single unit and includes its own high voltage power supplies within its chassis, similar to the transmitters for the APG-63, -65, and -70 radars for the F-15C/D, F/A-18, and F-15E fighters respectively. The transmitter employs a gridded traveling wave tube RF amplifier, similar to other Hughes radars. Because the transmitter is such a high power density package (KW/Ft³), it is liquid cooled.

The receiver/exciter LRU performs several functions usually requiring more than one LRU in contemporary radars. These include generating RF waveforms for amplification by the transmitter (exciter) and amplication, detection, and frequency down-conversion to baseband (receiver) of signals received from the antenna. The receiver/exciter also digitizes the received signal stream and performs pulse compression to enhance range resolution. Some of the receiver/exciter circuit modules are interchangeable with those of the APG-70 (F-15E) and APG-71 (F-14D) radars. It is forced air cooled.

The radar signal processor extracts target, images and measurement information from the received digitized signal stream and converts this information into a format usable by interfacing avionics or displays. In addition to a digital data output bus, it also has a video output bus that enables direct drive of cockpit displays. The RSP is fully programmable. Mode-unique software is recalled from its memory and used to control processing functions for each operating mode. The core signal processing modules of this unit are functionally interchangeable with those of the APG-65 (F/A-18) radar. The RSP has a throughput of 7.1 million complex operations per second and two million, 24-bit word (50 Mbits) bulk memory. This unit is forced air cooled.

The radar data processor is a dual central processor unit (CPU), MIL-STD-1750A Airborne Computer Instruction Set Architecture general purpose type computer. The RDP is the command controller for all radar units and serves as the radar terminal on the B-2 MIL-STD-1553A avionics data bus. Most of the RDP modules are interchangeable with those of the APG-70 (F-15E) and APG-71 (F-14D) radars. The RDP has a throughput of 2.5 million instructions per second and a one million, 16-bit word (16 Mbits) bulk memory. It also is forced air cooled.

The radar units have several features in common. All are connected by a dual (redundant) MIL-STD-1553 data bus for control and data passing function. They are nuclear hardened against transient radiation and electromagnetic pulse effects. To satisfy reliability requirements, LRU electronic components were selected to assure low electrical stress and, for active components, low junction temperatures. Finally, the units were designed to very stringent environmental requirements, some which are greater (vibration, for example) than those for similar environments for the Hughes line of fighter radars.

PHYSICAL PARAMETER OF THE RADAR

- Number of units (LRUs) in a shipset (one aircraft)	10
- Number of modules (SRUs) in a shipset	82
- Shipset toal weight	2100 lbs.
- Shipset total volume	52.5 cubic feet
- Operating prime power demand:	
- 400 Hz alternating current	22 KVA
- 24 Volts direct current	500 W
- Liquid cooling flow rate (55°F inlet temp.)	8 gallons per min.
- Cooling air flow rate (55°F inlet temp.)	27 pounds per min.

RADAR FSD AND PRODUCTION EQUIPMENT PRESENTLY ON ORDER

CONTACT	QUANTITY/ CONFIGURATION	NOTES
FSD	1 + Engineering Development Models	3 antennas, 5 transmitters & receiver/ exciters, 7 RSPs & RDPs
FSD	4½ Pre-production	4 shipsets, 1 spare string
FY87/88	5 Production	
FY89/90	5 Production	
FY87 Spares	Various Production	Misc. quantities of LRUs, SRUs and piece parts

B-2 Combined Test Force patch.

B-2 Northrop Test Team patch.

B-2 System Program Office patch.

Tom Copeland collection

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